Ministry
of the
Environment

Ontario

Water Resources
Report 8

Ground-Water Resources of the Duffins Creek-Rouge River Drainage Basins

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By
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MINISTRY OF THE ENVIRONMENT

Water Resources Branch

Toronto Ontario

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PREFACE

The Duffins Creek-Rouge River ground-water resources report is the eighth in a continuing series of reports of water-resources investigations being carried out by the Ministry of the Environment in an effort to provide the residents of Ontario with a sound knowledge of water resources in the Province. Investigations in the Duffins Creek-Rouge River drainage basins were undertaken because of rapid urban land use development north and east of Toronto, in which increased demands are being placed on ground water to meet domestic, municipal, industrial and irrigation requirements. It is hoped that with a thorough understanding of the resource capabilities and limits, a sound conservation and management plan can be formulated to insure continued optimum use of ground water in the area.

G. H. Mills, Director
Water Resources Branch

Toronto, Dec., 1977

ENGLISH - METRIC (SI) FACTORS

to convert	to	multiply by
inches (in)	centimeters (cm)	2.540
feet (ft)	meters (m)	0.305
miles (mi)	kilometers (km)	1.609
square miles (mi^2)	square kilometers (km^2)	2.590
cubic feet/second (cfs)	liters/second (l/s)	28.316
(Imperial) gallons (g)	liters (l)	4.546
(Imperial) gallons/day (gpd)	liters/second (l/s)	5.262×10^{-5}
(Imperial) gallons/day/ft^2 (gpd/ft^2)	meters/second (m/s)	5.663×10^{-7}
(Imperial) gallons/day/ft (gpd/ft)	square meters/second (m^2/s)	1.726×10^{-7}
(Imperial) gallons/minute (gpm)	liters/second (l/s)	.0758

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(in pocket)

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ABSTRACT

The investigation of ground-water resources in the Duffins Creek-Rouge River drainage basins defines in detail an inventory of the resource for the purpose of future ground-water development in a dynamic and rapidly changing land-use development area peripheral to Metropolitan Toronto. The report contains the results of an extensive subsurface geologic investigation aimed at locating and defining the major aquifer systems in the watershed. Detailed descriptions are given regarding these major aquifer systems, together with evaluations of the hydrochemistry of ground waters, ground-water use, its future development potential, and management planning concepts that can be applied to resolve existing and potential future ground-water quantity and quality related problems.

All the overburden lithologic units in the basin have been tentatively correlated with units in the Scarborough area north of Lake Ontario. These correlations provide a basis for defining the location, extent, and physical and hydraulic properties of 14 aquifer systems in the watershed. Wells in some of these aquifers are capable of producing up to 1000 gpm but these high capacities are not common. Most aquifers can readily yield up to 25 gpm to individual wells and there are areas in some of the aquifers where yields are likely to be more than 50 gpm. It is estimated that conservatively at least 44.3 mgd is recharged on an average to ground water. This is equivalent to an annual infiltration of 4.5 inches of precipitation over the basin.

Natural ground-water quality in the overburden is generally acceptable for domestic and irrigation uses, but water from bedrock can be high in total dissolved solids and often contains high concentrations of chloride and hydrogen sulfide gas.

Ground water is the primary source of supplies for most of the major requirements in the basin, with municipal consumption being almost 25 percent of all the large-scale takings. Other major uses include industrial and commercial takings, golf course and agricultural irrigation, and ground water used for private recreational ponds.

Ground-water management concerns relate to regulating flowing wells, avoiding water-level interference situations, and formulating policies to avoid ground-water quality impairment by such as sanitary landfill operations, domestic septic systems in concentrated areas, agricultural fertilizer practices, and pollution due to accidental liquid spills and road salts. To this end, maps are presented to assist in determining the potential hazards of ground-water contamination in the watershed.

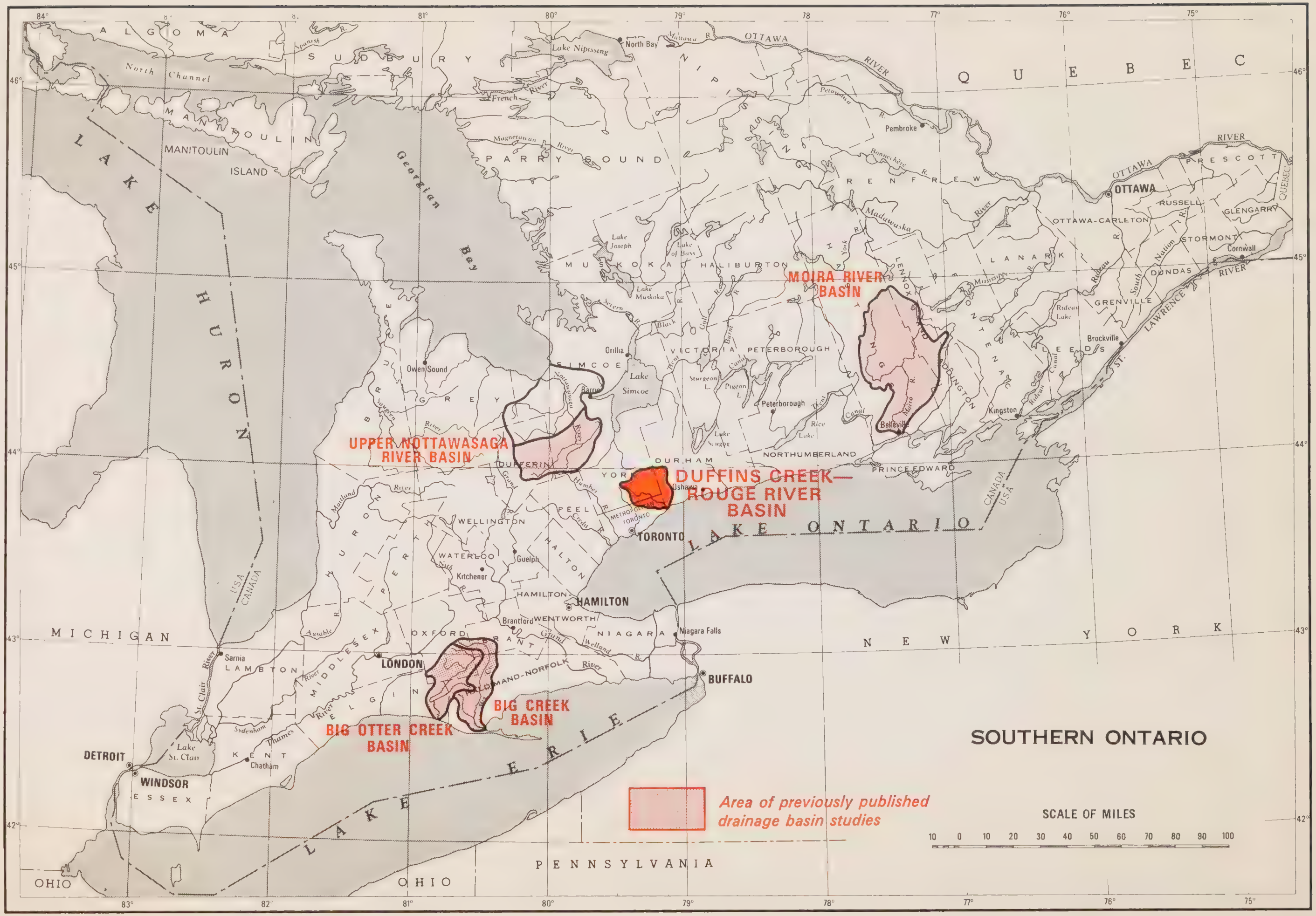


Figure 1. Location and extent of the Duffins Creek-Rouge River drainage basins.

INTRODUCTION

PURPOSE AND SCOPE

This report is part of the Ministry of the Environment's continuing program of water-resources inventory evaluations in the Province. The Duffins-Rouge basin was selected for study because of the area's proximity to rapid urban development north and east of Toronto, including a major townsite development in the eastern part of the basin.

The urban pressures placed on an otherwise rural agricultural area have affected notable changes in land-use patterns in the basin. These changes have resulted in rapid increases in ground-water demand in certain areas of the watershed, with periodic shortages and overdevelopment of ground-water resources in the Rouge River basin in the Unionville-Markham area, and inadequate ground-water availability affecting proposed development in the Duffins Creek basin to the east. In association with major developments such as the North Pickering Project in the Duffins Creek basin, the consumptive use of, and pollution hazards to ground water are expected to increase in the future.

Preliminary hydrologic field work in the basin was carried out during 1970 and 1971, and detailed work was undertaken in 1974. Data collation and analyses were done in 1975. The study was inactive in 1972 and 1973. During the three years of field activity, the work consisted of extensive subsurface hydrogeologic investigations through test drilling, the establishment of an observation-well network to study water table and piezometric level fluctuations, and the sampling of wells for water quality analyses. Reconnaissance surface geologic mapping was also carried out.

The report deals in detail with overburden stratigraphy in the watershed and major aquifers are delineated and discussed. Aquifer characteristics are described in terms of location, extent, materials, and hydrogeologic properties. Water-level fluctuations and water quality data and analyses are presented, and ground-water uses, conflicts and management planning are discussed. The basic data and interpretations of ground-water resources presented in this report can form a reliable base on which future planning of land-use development and associated ground-water uses can be rationalized.

LOCATION

The watershed covers an area of 268.5 square miles northeast of Toronto and is bounded by longitudes 79°01' and 79°29' and by latitudes 43°03' and 44°47' (Figure 1). The main drainage areas of the basin involve Duffins Creek, the Rouge River, and an area in the south that is drained by a number of small creeks that flow directly into Lake Ontario. Petticoat Creek is the largest of these small streams. Individual drainage areas are as follows (Ont. Dept. of Planning and Dev't, 1956):

Stream	Drainage Area (sq mi)	Percentage of Total Basin
Duffins Creek	119.9	45
Rouge River	129.7	48
Petticoat Creek Plus Others	18.9	7
Total	268.5	100

For purposes of this report, the area covered by all three drainage systems will be referred to as the "Duffins-Rouge" basin, or the "basin".

In terms of political geography, most of the basin is divided between the Regional Municipality of York in the west and the Regional Municipality of Durham in the east, with only a small area in the mid-southern part of the basin located in the Municipality of Metropolitan Toronto.

The largest urban centres in the basin are: Markham, Stouffville, Pickering, Unionville, and Claremont. The centres of Richmond Hill and Ajax are located only partially in the watershed.

PREVIOUS INVESTIGATIONS

Past investigations directly related to hydrogeology in the basin have been published by the Federal Government in a series of reports dealing with ground water in the former townships of Whitchurch (Hainstock et al, 1952), Markham (Caley et al, 1948), Scarborough (Hainstock et al, 1948), Uxbridge (Gadd, 1950), and Pickering (Caley et al, 1947). Each of these publications follows the same format of subject presentation and discusses in general terms ground-water occurrence, use, availability, and water quality in each of the former townships. Delineation of aquifers is not attempted but a brief description of permeable deposits in each area is provided.

On a much larger scale of investigation, Haefeli (1970) discusses the regional ground-water flow between Lake Simcoe and Lake Ontario, and a large portion of the Duffins-Rouge basin is covered by this study area. The report deals with ground-water quality in detail and presents a statistical review of hydrogeologic properties of the Quaternary deposits in the study area. The report also presents several alternate ground-water flow patterns in the area between Lake Simcoe and Lake Ontario.

Ostry's (in preparation) report on the hydrogeology near the mouth of Duffins Creek is the only other report to relate directly to ground water in the basin.

The main geologic publications covering partial areas of the basin include Pleistocene geology reports by Karrow (1967, 1970) in the Scarborough and Thornhill areas, by Hewitt (1969) and Hewitt and Karrow (1963) regarding sand and gravel deposits in the watershed, and by Dreimanis and Terasmae (1958) regarding stratigraphy of the Wisconsinan glacial deposits in the Toronto area. Information on bedrock geology has been published by Rogers et al (1961), Karrow (1970) and Ostry (in preparation). Rogers et al present only a preliminary bedrock topography map for the Metro Toronto area, and the reports by Karrow and Ostry describe bedrock geology and topography in the Thornhill and the lower part of the Duffins Creek areas, respectively. General bedrock geology reports by Caley (1940) and Hewitt (1972) provide information on bedrock geology in the basin in the context of Palaeozoic geology in the Toronto-Hamilton area, and in southern Ontario on the whole.

A conservation report was prepared by the Ontario Department of Planning and Development (1956) for the Rouge, Duffins, Highland, and Petticoat watersheds. Chapters in the report on land use and water include relevant discussions of physiography and overburden geology, general surface-water hydrology, and flood-flow analyses at points on the Rouge River and Duffins Creek. Other chapters in the report deal

with history, forestry, wildlife, and recreation in the four watersheds.

Information on file with the Ministry of the Environment includes data in the Duffins-Rouge basin on water-well construction, ground-water use, water-supply investigations, and past well-interference and ground-water contamination problems investigated by the Ministry. Two internal reports on water supply and pollution control (OWRC 1966, 1968) deal with hydrogeology in the regional municipalities of York and Durham. Data on ground-water occurrence, distribution, availability, and water supply in the two publications have provided valuable background information for the present inventory study.

ACKNOWLEDGEMENTS

The collection of subsurface geologic data and test drilling were carried out under the direction of K. Goff in 1970 and 1971, and by I. Steltner in 1974. D. Sharma was responsible for establishing and maintaining water-level and precipitation gauges in the observation-well network, as well as directing the water sampling program in 1970. The 1974 water sampling program was directed by I. Steltner.

Data compilation and analyses were assisted during the summers by R. Hillary, R. Rae, K. Raven, A. Tsai, and C. Warner. Text of the report was reviewed critically by R. C. Hore.

Appreciation is extended to members of the Metropolitan Toronto and Region Conservation Authority for their co-operation during the study, and especially to members of staff at Bruce's Mill and Claremont conservation areas for their diligence in measuring water levels in observation wells at the two sites.

Special thanks are extended to residents who permitted the installation of water-levels recorders on their wells, and to residents who provided water samples during the ground-water quality survey in the basin.

GEOGRAPHY

PHYSIOGRAPHY

The Duffins-Rouge basin contains three main physiographic regions, each region having its own characteristic geologic surficial deposits, land terrain, and range of land surface elevations (Map 1). The three regions are classed as:

1. The Oak Ridges Moraine
2. The Central Till Plain
3. The Lake Iroquois Plain

The Oak Ridges Moraine region is located between the elevations of approximately 900 and 1300 feet, and the northern boundary of the drainage basin is located in this region. The region is a distinctive area of high ridges and hills of sand and gravel that are usually covered by a layer of sand till. Local relief is high, especially in the eastern parts of the region where sand hills are often more than 100 feet high. There are only a few streams on the moraine itself as most stream development occurs near the base of the moraine at an approximate elevation of 1000 feet. Small local swamps are numerous.

The Central Till Plain is the largest physiographic region in the basin and is located between the elevations of approximately 450 feet in the south and 900 feet in the north; most of the land surface is between 600-800 feet. The majority of the region is covered by the Halton Till, but there are sizeable patches of surface sand and clay in the region. Large areas of surficial clay deposits are located between Stouffville and Claremont, and west of Markham (Map 5). The land surface consists of gently rolling, low-relief hills with the largest relief provided by stream valleys that are incised 20-30 feet into the rolling plain in the north, and 50-100 feet in the southern parts of the region.

The Lake Iroquois Plain region extends northward from Lake Ontario and lies between the elevation of Lake Ontario, at approximately 245 feet, and the base of the Iroquois shoreline at an elevation of about 450 feet. The region consists primarily of a gently rolling, bevelled till plain with occasional flat sand and clay plain areas that formed the bottom of glacial Lake Iroquois. Deeply-eroded stream valleys of the Rouge River and Duffins Creek provide the largest relief in the region. The Rouge River valley near Rouge Park is approximately 125 feet deep, while the Duffins Creek valley to the east has been eroded close to 100 feet below the surrounding land surface. Numerous gravel-pit operations in the northern section of the region follow the general trend of the Iroquois shoreline and provide artificial relief to the landscape in the otherwise flat terrain immediately south of the old shoreline bluffs.

DRAINAGE

The watershed area is drained by the Rouge River in the west, by Duffins Creek in the east, and by Petticoat Creek and other small streams that flow directly into Lake Ontario around Frenchman's Bay (Map 1). The largest tributary of the Rouge River is Little Rouge Creek, which drains the entire eastern part of the Rouge River basin; Bruce and Beaver creeks are smaller tributaries that branch from the Rouge River

west of Markham. The largest tributary of Duffins Creek is West Duffins Creek, which drains the entire western portion of the Duffins Creek basin. Other sizeable tributaries of Duffins Creek include Michell Creek, Brougham Creek and Ganatsekiagon Creek.

The major streams in the basin trend generally in a northwest-southeast direction, and for the most part, the drainage pattern is parallel. There is virtually no stream development on the Oak Ridges Moraine because most of the precipitation infiltrates into the ground or is gathered into enclosed depressions that are found in the area. Ground-water discharge, either in the form of flowing wells as in the case northwest of Stouffville, or as spring seepage, is a noticeable feature and is responsible for the stream development at the base of the Oak Ridges.

Stream valley development for most streams is generally small in the northern half of the basin, except for Duffins Creek which has a well-defined, deep valley throughout most of its length. Well-defined stream valleys begin to develop in the southern half of the basin and the deepest parts of the valleys occur in the approximate area of the Lake Iroquois shoreline. At some locations in the area of the shoreline, the Rouge River valley is more than 125 feet deep and the Duffins Creek valley exceeds 100 feet in depth. At its mouth, the Rouge River valley is approximately 75 feet deep, while Duffins Creek has virtually no distinct valley at its outlet into Lake Ontario.

Streambed gradients in the basin are variable but generally steep. The gradient along the Rouge River varies from approximately 132 feet per mile near its source, to 13 feet per mile as it approaches Lake Ontario. The Little Rouge Creek gradients range between 208 feet per mile over for the first 0.6 miles, to about 44 feet per mile over the last 8 miles. The first 3 miles of Duffins Creek has a gradient of 121 feet, dropping to 20 feet per mile over the last 4 miles. West Duffins Creek has a gradient range of 50 feet per mile over the first 4.5 miles to 54 feet per mile over the last 5 miles. A more detailed account of gradient profiles is given by the Department of Planning and Development (1956).

Land drainage throughout the basin is good and there are no extensive swampy areas in the watershed. Only localized swampy conditions exist in some parts of the Oak Ridges and in small portions of the main valleys of Duffins Creek and Rouge River.

CLIMATE

There are a total of 17 meteorologic stations in operation in and around the basin (Map 2). However, the type and continuity of climatic data are variable among the stations and data from all stations make it difficult to compare the basic climatic factors of temperature and precipitation over concurrent periods throughout the basin. There are only three stations that have comparable long-term averages of both temperature and precipitation:

1) Oak Ridges,
2) Richmond Hill,
3) Pickering Audley.

The Oak Ridges station is at an elevation of 1115 feet (above sea level), and indicates climate in the northern part of the basin. The Richmond Hill station, at an elevation of 764 feet, indicates climate in the central area, and the Pickering Audley station, at an elevation of

300 feet, is in the south near Lake Ontario.

Both temperature and precipitation averages do not vary significantly at the three stations, as shown by data in Table 1. In general, the mean daily temperatures at the Oak Ridges station in the north tend to be lower during the winter and higher during the summer than at Pickering Audley in the south, but the differences are small. The same applies for extreme maximum and minimum temperatures. Mean annual temperatures at the three stations are: Oak Ridges - 44.4°F; Richmond Hill - 44.6°F; Pickering Audley - 44.0°F.

Precipitation is slightly higher at the Oak Ridges station than at the other two stations; the annual mean at Oak Ridges is 32.23 inches, compared to 30.57 in the middle of the basin at Richmond Hill, and 31.91 inches in the south at Pickering Audley.

POLITICAL AND ECONOMIC GEOGRAPHY

The Duffins-Rouge basin lies within the jurisdictions of three major municipalities of the Province of Ontario: the regional municipalities of York and Durham, and the Municipality of Metropolitan Toronto. Each of these municipalities is divided into sub-units which are identified in Table 2 and located on Map 6.

Most of the western section of the basin occupies the southeastern corner of the Regional Municipality of York, which was formerly the County of York. Parts of the towns of Markham, Richmond Hill and Stouffville are included in this area. The eastern portion of the basin extends into the southwestern section of the Regional Municipality of Durham, which includes the towns of Pickering and Ajax, and the Township of Uxbridge. Prior to January 1, 1974, this portion of the regional municipality was part of the County of Ontario.

The basin is in a general state of economic transition from predominantly rural to urban-oriented activities. Intensive agricultural activity is gradually giving way to functions of urban service and industry associated with Metropolitan Toronto and the outlying communities of Richmond Hill, Markham, Unionville and Stouffville. One new project, the North Pickering Project (NPP), in particular may determine the direction of future economic development in the watershed. This is a provincially planned urban development complex in the Duffins Creek basin south-southeast of Brougham. Associated with the project are a number of residential, commercial and industrial developments which will intensify urbanization in the area and which could eventually change the existing agricultural-based economy in the watershed.

POPULATION AND LAND USE

The Duffins-Rouge basin is located on the northern perimeter of Metropolitan Toronto, one of the fastest growing urban areas in North America. The urban development in Toronto has a distinct spill-over effect and is producing a land use and population mosaic in the basin that is characteristic of a rapidly developing area.

In 1975 the basin supported a population of approximately 88,150 persons (Table 2), and settlement density continues to be focused in the extreme western and southeastern portions of the basin in the towns of Richmond Hill and Ajax. The communities of Markham, Unionville and Stouffville are also major population centres. Urban settlement in the

Table 1. Long-Term Temperature and Precipitation Data (1941-70) at Oak Ridges, Richmond Hill and Pickering Audley Meteorologic Stations

		Months												
Temperature (°F)		J	F	M	A	M	J	J	A	S	O	N	D	Annual
Mean Daily	O.R.	18.8	19.5	28.9	42.6	53.5	64.6	69.0	66.7	59.4	49.0	36.6	23.9	44.4
	R.H.	18.8	20.0	29.0	42.8	53.7	64.3	68.6	67.2	60.3	49.1	37.5	24.2	44.6
	P.A.	19.6	20.4	28.8	42.3	52.3	62.2	66.9	66.0	59.1	48.0	37.4	24.6	44.0
Extreme Max.	O.R.	58	53	79	83	90	96	104	100	96	86	69	60	104
	R.H.	56	51	69	84	90	94	95	93	93	81	74	63	95
	P.A.	57	51	69	84	91	95	94	92	90	81	73	58	95
Extreme Min.	O.R.	-25	-30	-12	4	23	24	36	34	28	15	-5	-29	-30
	R.H.	-16	-18	-9	12	22	33	40	39	26	18	7	-13	-18
	P.A.	-22	-20	-9	12	21	32	36	33	25	15	1	-17	-22
Precipitation (in.)														
Mean Total	O.R.	2.44	2.11	2.38	2.73	2.88	2.52	3.50	3.02	2.61	2.64	2.75	2.65	32.23
	R.H.	2.36	2.01	2.26	2.60	2.88	2.35	3.00	3.02	2.61	2.46	2.56	2.46	30.57
	P.A.	2.25	2.26	2.83	2.64	2.87	2.51	2.84	2.90	2.63	2.74	2.72	2.72	31.91
Greatest Total in 24 Hrs.	O.R.	1.40	1.56	1.50	2.12	2.32	2.06	2.90	3.88	1.97	4.80	2.30	1.56	4.80
	R.H.	1.00	1.04	0.70	0.93	1.45	1.68	2.04	2.03	1.75	1.34	1.82	1.20	2.04
	P.A.	1.21	1.23	0.67	1.56	1.87	1.53	2.35	1.35	1.58	1.10	1.55	1.33	2.35

O.R. - Oak Ridges
R.H. - Richmond Hill
P.A. - Pickering Audley

southern sectors of the towns of Markham and Pickering is a significant demographic characteristic of the Duffins-Rouge basin. In addition, as the North Pickering Project is established, and as the provincial government continues to encourage residential development east of Toronto, intensified urban settlement is expected to continue and spread over much of the watershed.

With regard to land use, agricultural use of lands in the basin exceeds non-agricultural use by a ratio of 3 to 2 (Table 2). The non-agricultural category consists of industrial, commercial, residential, institutional and undesignated uses, and it is expected that these uses will intensify and eventually exceed agricultural use on the basin average. However, agricultural land use will likely continue to be primary for some time in the northern areas of the basin.

Table 2. Population and Land Use, 1975

Municipality	Area in Basin (sq mi)	1975 Population	Population Density (persons/ sq mi)	Non-Agric: Agric. Land Ratio
Regional Municipality of York				
Town of Aurora	1	200	200	56:44
Town of Markham	72	29,600	400	36:64
Town of Richmond Hill	20	15,100	750	50:50
Town of Whitchurch-Stouffville	34	5,350	160	17:83
Regional Municipality of Durham				
Town of Ajax	12	11,900	950	43:57
Town of Pickering	79	21,800	270	N.A.
Township of Uxbridge	25	4,850	60	47:53
Metropolitan Toronto				
Borough of Scarborough	13	2,350	180	87:13
Total Basin	256	88,150	330	41:59

GEOLOGY

BEDROCK GEOLOGY

Stratigraphy

Upper Ordovician shales of the Whitby and Georgian Bay formations underlie the watershed and their distribution, as mapped by Hewitt (1972), is indicated on Map 3. Hewitt describes the Whitby Formation as grey and black shales that are approximately 290 feet thick near Lake Ontario, and the Georgian Bay Formation as approximately 600 feet of grey shale with interbeds of limestone.

Drilling of 19 test holes by the Ministry of the Environment during field investigations in 1971, 1972 and 1974 indicated grey shales to be the most common bedrock directly underneath the overburden in the area. However, in several of the test holes it was difficult to differentiate between the dark grey till and the underlying grey shales because of the soft, weathered nature of the bedrock. This weathering is usually restricted to the first five feet of the top of the rock. In well 10255, approximately 17 feet (of the 20 feet of bedrock penetrated) of soft, grey, weathered shale was encountered beneath a grey silt till (Appendix A). At this site the exact bedrock/overburden contact was difficult to determine during drilling, but the electrical resistivity log of the test hole indicated a sharp decrease in resistivity at the suspected contact. Similar difficulties in determining the top of the bedrock surface are indicated by drillers who have worked in the area. Consequently, some of the "grey" and "black" clay identified on top of bedrock in drillers reports may in fact be weathered shale.

Topography

The bedrock topography has been presented by Haefeli (1970) for the area between the Oak Ridges and Lake Ontario. His report is the only publication that covers a large portion of the Duffins-Rouge basin. The topography is illustrated by 100-foot contour intervals and covers mainly the Rouge River basin in the western part of the watershed. Ostry (in preparation) has prepared a bedrock topography map for the area of Duffins Creek adjacent to Lake Ontario, and an earlier map by Rogers et al (1961) of the Metropolitan Toronto region touches only a small area of the basin in the Borough (formerly the Township) of Scarborough. Watt's (1957) work in the Borough (formerly the Township) of North York and Karrow's (1970) bedrock topography map in the Thornhill area are both outside the basin boundaries. However, all these references were consulted and their data and topographic trends carefully considered in determining the bedrock topography shown on Map 3.

The present bedrock topography map has been based on data obtained from water-well records filed with the Ministry as of December 1974, plus data gathered from test drilling by the Ministry in 1971, 1972 and 1974. The majority of bedrock well locations in the basin have been field checked and verified, but in certain areas, notably at Unionville, field checking was not possible due to urbanization.

The distribution of bedrock data is generally good throughout most of the basin, except on the Oak Ridges Moraine where only a few water wells have been drilled into rock.

Bedrock elevation trends throughout most parts of the basin indicate a complex system of bedrock channels and highs that have probably resulted from erosion of the bedrock surface by drainage systems older than the last major (Wisconsinan) glaciation.

Highest bedrock elevations occur in the northern parts of the watershed beneath the Oak Ridges Moraine where the shale surface in one well just north of the basin is shown to be as high as 660 feet. Southward from the moraine the bedrock elevation decreases towards Lake Ontario where well records indicate the elevation of the rock surface in many areas to be less than 200 feet.

A prominent feature of the bedrock surface topography is the generally northwest-southeasterly trend of most of the drainage patterns in the watershed. This trend is well displayed by the system of valleys trending northwest from Lake Ontario between Ajax and Rouge Hill where outlets to two large valley systems are evident. One of these valleys runs diagonally across the basin from Squire's Beach to east-northeast of Markham, and then swings to the west just south of the boundary between the Town of Whitchurch-Stouffville and the Town of Markham. The other valley is close to the eastern boundary of the basin and parallels the boundary northward. However, data on this system are sparse in the northern parts of the basin and its presence and shape is highly interpretive. Neither of these valleys is known to contain sand and gravel.

OVERBURDEN GEOLOGY

Surficial Deposits

A map of surficial deposits in the basin (Map 5) was compiled from existing publications covering the watershed, supplemented by field examinations during 1970 and 1971. The map was compiled mainly on the basis of information shown on Geologic Map 2124 published by Hewitt (1969), with incorporated modifications according to Karrow's (1967) report on the surficial deposits in the Scarborough area, and on mapping carried out by Gwyn and DiLabio (1973) in the Newmarket area.

All surface Pleistocene deposits in the basin are attributed to the latter stages of Wisconsinan glaciation (Karrow, 1967; Hewitt, 1969; Gwyn and DiLabio, 1973). These deposits are related to environments in which materials were laid down under glacial ice, in lakes and ice-marginal ponds, in meltwater channels and streams in front of and between ice lobes, and in ancestoral Lake Ontario known as Lake Iroquois. The materials vary in composition, texture, particle size, continuity and extent. Deposits laid down under glacial ice consist of poorly sorted clay, silt or sand tills that are usually very compact, poorly permeable, and often continuous over large areas. Materials deposited in lakes and ice-marginal ponds in the area are relatively well-sorted and occur as beds of clay, silt and sand. Although some of these deposits are extensive, they are usually not as continuous or extensive as till sheets. Fluvial deposits consist of well-sorted sands and/or gravels and have a generally limited continuity and areal extent.

Each of the different deposits are associated with specific landforms that portray the mode of deposition. The Oak Ridges Moraine is a prominent height of rolling land in the northern part of the basin and reflects the deposition of sand and gravel in a primarily fluvial environment. A complete description of these materials is discussed

under "Kame, Ice-Contact and Outwash Deposits". The rolling till plain area covering most of the central region of the basin is covered by the Halton Till, which was deposited underneath the last major Wisconsinan ice sheet in the area. This till plain has been mapped as "Glacial Deposits" shown on Map 5. There are two lacustrine plains in the watershed, each covered by stratified sand, silt and clay; one plain reflects deposition in ice-marginal pondings in the middle sections of the basin (shown primarily as "Fine-Grained Lacustrine and Pond Deposits" on Map 5), and the other is the result of deposition of materials in Lake Iroquois south of the beachline. These latter deposits consist of both fine- and coarse-grained materials of clay, silt and sand. The Iroquois beachline itself is a well-defined bluff with well-sorted beach sands and gravels to the south of it.

Alluvial and Swamp Deposits .... There are no extensive areas of swamp or alluvial deposits in the watershed. The most significant of the deposits that do occur in the basin are found in small swamps on the Oak Ridges Moraine, on alluvial terraces and swamps adjacent to the lower sections of Duffins Creek and the Rouge River, and at Frenchman's Bay. The muck deposits in swamps on the Oak Ridges are confined to small closed depressions fed by surface runoff and often by shallow ground-water levels in the area. The deposits are generally thin.

The largest deposits of alluvial sands and gravels occur on stream terraces adjacent to Duffins Creek and Rouge River, and are the result of recent flooding and deposition of sediments during high water stages in the streams. At most localities the deposits are thin and vary in composition within short distances from well-sorted sand and gravel to poorly-sorted sand, gravel, silt and clay.

Fine-Grained Lacustrine and Pond Deposits .... There are two main areas in the basin where fine-grained deposits of fine sand, silt and clay were deposited in glacial pondings and ice-marginal lakes.

One area is located in an east-west band in the middle of the basin where surface silts and clays were probably deposited in ponds fed by meltwaters from a retreating glacial ice front. The other area is located south of the Lake Iroquois beachline where similar fine-grained deposits represent near-shore sediments in a large glacial lake that was the forerunner of present day Lake Ontario.

Within the first area, the surface silt and clay deposits west of Claremont and northwest of Markham are stratified and in some localities resemble a varving of the clays. For the most part though, the stratification is faint and difficult to distinguish. The deposits are usually less than 5 feet thick, except in local depressions and stream valleys where the thicknesses may exceed 10 feet.

Within the second area on the Lake Iroquois plain northeast and southwest of Pickering, the fine-grained sediments occur as a thin veneer on the Halton Till.

Coarse-Grained Lacustrine and Pond Deposits .... Deposits of surface sands represent the generally coarse-grained fraction of materials deposited in lacustrine and ice-marginal pondings during the retreat of the ice from the basin. The sands southwest of Unionville were deposited in a local ice-marginal ponding during deglaciation of the area. The sands overlie lake clays and have an average thickness of approximately 3 to 4 feet (Karrow, 1967, p.40).

The sands south of the Lake Iroquois shoreline were deposited in the shallow-water environment of the glacial lake and overlie the Halton

Till that otherwise blankets the surface. Although most of the sands are fine-grained, a gradation into coarser-grained materials occurs as the sands become interbedded with shoreline gravels towards the north. The sands and gravels along or close to the old shoreline commonly exceed 15 feet in thickness, whereas the surface sands towards the south are less than 5 feet thick in most locations.

Kame, Ice-Contact and Outwash Deposits .... The kame, ice-contact and outwash deposits consist of coarse-grained sands and/or gravels deposited by glacial meltwaters in contact with or in front of a retreating ice margin. Coarse gravels make up a large proportion of the kame and ice-contact deposits, whereas outwash consists mainly of coarse- to medium-grained sand.

The most extensive kame, ice-contact and outwash deposits of sands and gravels in the basin are those associated with the Oak Ridges Moraine. The stratified surface and near surface sands and gravels were deposited by glacial meltwater derived from a receding ice front to the south. A later readvance of the ice covered most of the fluvial materials except in the northeastern part of the basin where large areas of primarily sand are exposed on the surface of the moraine. Scattered patches of sands and gravels are also evident in gravel pits west of Lemonville, and in surface deposits west of Preston Lake and west of Gormley.

The thickness of the sands and gravels is variable, but the deposits are generally thicker and coarser in the eastern parts of the Oak Ridges than in the west. In test hole 4885 in the eastern part of the moraine, the sands and gravels have a total thickness of approximately 244 feet; however, there are only 70 feet of similar deposits under a till cover in test hole 10548 in the west (Appendix A).

Only a few, scattered surface deposits of outwash occur in the basin. They consist mainly of a thin mantle of medium-grained sand over sand till, and the largest areas of these sands have been mapped by Karrow (1969) near Cherrywood.

Beach Deposits .... Deposits of beach sands and gravels are exposed on the surface south of the Lake Iroquois shoreline. These coarse-grained deposits were derived, at least in part, by erosion of the underlying till surface by lake waters, but in places a reworking of older gravels within or under the Halton Till is indicated. In some gravel pits the well-sorted beach gravels are lying on ice-contact or outwash stratified sands and gravels.

All the gravels are exploited extensively by commercial gravel operations and as a result, the deposits in the area of the Borough of Scarborough are largely depleted (Hewitt, 1969, p.10). There are larger reserves of gravel towards the east but these are also being rapidly mined for aggregate for the construction industry.

Glacial Deposits .... Glacial deposits consist of an unsorted debris of sand, silt, clay and stones deposited at the base of the glacier and are commonly known as "till". In this area the till was originally named as "Leaside Till" by Terasmae (1960). In a more recent publication, Karrow (1974) indicates that the Leaside Till is directly equivalent to the Halton Till in the Hamilton area, and suggests that the latter name be also adopted in the Toronto vicinity. This convention will be used in this report, i.e., the surface till previously referred to as Leaside Till will be called the Halton Till.

The Halton Till is commonly a silty sand till, varying in some

areas to a silt till and becoming mainly a sand till on the Oak Ridges.

Detailed grain-size analyses, carbonate ratios and pebble counts of the Halton Till samples are discussed in the section dealing with cross sections that illustrate the total overburden stratigraphy in the watershed.

Stratigraphy of Buried Deposits

Information on overburden stratigraphy in the basin has been obtained primarily from water-well records submitted by drillers to the Ministry of the Environment and from geologic data obtained through 19 test holes drilled by the Ministry during the study. The locations of these holes are shown on Figure 17 in Appendix A. All test holes were logged by on-site project geologists during drilling, and the classification of materials was made on the basis of visual inspection of split spoon samples. Down-the-hole geophysical logs were made of each test hole (Appendix A).

Unconsolidated overburden deposits overlying bedrock are generally 200-300 feet thick throughout most of the basin, with thicknesses in excess of 500 feet found in the Oak Ridges Moraine (Map 4). Within these thicknesses there are materials that have been deposited during a number of glaciated and ice-free intervals in the area. The deposits related to each period vary in grain size, sorting, texture and lateral continuity. The lateral continuity is especially important in correlating similar deposits in the basin and is discussed at length.

Buried deposits of till vary from compact sand, to silt, to clay tills (Table 3). Subsurface continuity of tills can be traced throughout much of the basin and consequently makes the correlation of the tills and deposits between the till sheets easier. Buried lacustrine sediments of sand, silt and clay occur between the till sheets, but because the continuity of these deposits is generally less extensive and because of facies changes within the deposits, the direct correlation of lacustrine deposits can be difficult. The correlation of fluvial deposits of sorted sands and gravels is most difficult because of their limited extent, the wide range of possible facies changes, and their limited thicknesses.

In order to understand the variety of materials present in the overburden, a brief summary of the historical geology in the area is necessary. There is evidence of at least two stages of major glaciation in southern Ontario during the Pleistocene times. These are referred to as the Illinoian and Wisconsinan glaciations. Evidence of the older Illinoian glaciation in the watershed is described by Karrow (1967) who considered the clayey sand till with shale fragments found on bedrock along the Rouge River as Illinoian. This glacial period was followed by the Sangamon interglacial stage, during which time beds of stratified sand, silt and clay were deposited in what is referred to as the Don Formation (Terasmae, 1960). The early stage of the subsequent Wisconsinan glacial period is evidenced by lacustrine deposits of sand, silt and clay in the Scarborough Formation.

There were two major ice advances during the Wisconsinan, separated by an interstadial period of cool but ice-free climate. The earliest Wisconsinan ice deposited the Sunnybrook Till, and the interstatial

period that followed is recorded by sand, silt and clay deposits of the Thorncliffe Formation. A subsequent (and last major) Wisconsinan ice deposited the Seminary and Meadowcliffe tills, as well as the Halton Till found on the surface throughout much of the watershed.

During the late stages of the Wisconsinan glaciation, the ice sheet thinned in the vicinity of the present-day Oak Ridges Moraine and eventually split into two major ice lobes. One lobe retreated northward into the Lake Simcoe area and the other southward towards Lake Ontario. Initial meltwater from the lobes deposited thick sequences of kame, ice-contact and outwash sands and gravels, which formed much of the core of the Oak Ridges Moraine.

Several subsequent fluctuations of the ice front covered the Oak Ridges intermittently with thin till sheets before the southern ice lobe finally withdrew into the Lake Ontario basin. A similar retreat of the northern lobe occurred into the Lake Simcoe area (Deane, 1950). It was during and subsequent to the withdrawal of the Lake Ontario lobe that the present-day surface materials throughout the basin were laid down to mantle the Halton Till. The fine-grained silt, clay and fine sand indicate the existence of ice-marginal pondings in the centre of the basin, whereas coarse-grained pond and outwash sands north of the Lake Iroquois shoreline indicate deposition in shallow ice-marginal pondings and associated rivers. As the southern ice lobe gradually receded into the Lake Ontario basin, a large glacial lake known as Lake Iroquois was formed. It left a prominent shore bluff as it eroded into the underlying Halton Till and redeposited the coarser fraction of the till as beach sands and gravels. In some localities Lake Iroquois waters eroded through the top till to expose underlying ice-contact gravels which were subsequently reworked into beach deposits. Recession of Lake Iroquois to the present-day Lake Ontario shore bluffs followed, with the erosion of modern stream terraces sculpturing the land into the topography seen today.

Cross Sections .... The stratigraphy of the total thickness of overburden deposits in the basin is illustrated by a composite, schematic cross section shown in Figure 2. The cross section is based on a number of individual sections drawn throughout the basin using accurate geologic data obtained from the 19 test holes drilled by the Ministry. The correlation of till units is based on grain-size analyses, calcite/dolomite (carbonate) ratios, and on pebble counts, all of which are tabled in Appendix B. A summary of these analyses is shown in Table 3.

For purposes of identification, the overburden stratigraphy in the basin is divided into four units:

I Upper Drift
II Middle Drift
III Interstadial Drift
IV Lower Drift

Each of the four units represents a major period of deposition in the area and except for the Lower Drift, each can be identified in most areas of the basin. Also, permeable deposits are found in all but the Lower Drift, with major buried aquifers occurring in the Interstadial and Middle Drift units. These correlations are shown on the table accompanying Figure 2. The contacts between adjacent drift units were identified as follows:

1) the contact between units IV and III was drawn on top of the readily identifiable basal till in the Lower Drift;

PRESENT CLASSIFICATION	MATERIAL	TENTATIVE CORRELATION WITH STRATIGRAPHY BY KARROW (1967)	AQUIFERS IN DUFFINS-ROUGE BASIN
I UPPER DRIFT	Mainly till; lenses of sand, silt, clay; sand and gravel in Oak Ridges	Early lakes and streams Halton Till	Oak Ridges Aquifer Atha Aquifer
II MIDDLE DRIFT	Mainly till; some sand, silt, clay; sequences of ice-contact sand and gravel	Lakes and streams Meadowcliffe Till Lakes and streams Seminary Till	upper Brougham Aquifer upper & lower Victoria Aquifers upper Markham Aquifer upper Unionville Aquifer Green River Aquifer
III INTERSTADIAL DRIFT	Mainly sand, silt, clay; lenses of till; some ice-contact sand and gravel	Thorncliffe Fmn Sunnybrook Till Scarborough Fmn	lower Markham Aquifer lower Unionville Aquifer lower Brougham Aquifer Greenwood Aquifer Pickering Aquifer Cedar Grove Aquifer
IV LOWER DRIFT	Till	York (Illinoian) Till	

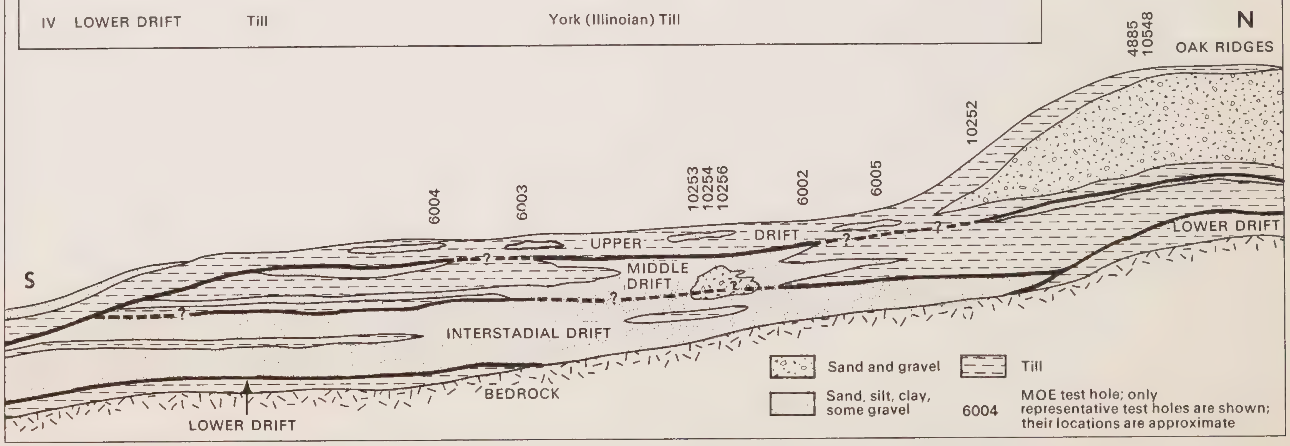


Figure 2. Composite schematic north-south cross section of overburden stratigraphy in the Duffins-Rouge basin.

Table 3. Summary of Till Analyses

Drift Unit*	Grain-Size Analysis Clay (%)	Silt (%)	Sand (%)	Calcite Dolomite Ratio	Pebble Count Limestone (%)	Dolomite (%)	Shale (%)	Sandstone (%)	Crystalline (%)
I	22 (43)	33 (43)	45 (43)	5.3 (40)	79 (38)	3 (38)	2 (38)	0 (38)	16 (38)
II	27 (27)	40 (27)	33 (27)	3.2 (27)	81 (19)	7 (19)	2 (19)	0 (19)	10 (19)
III	36 (4)	42 (4)	22 (4)	2.4 (4)	N.A.				
IV	14 (7)	20 (7)	66 (7)	4.6 (7)	12 (3)	1 (3)	87 (3)	0 (3)	0 (3)

* see Figure 2

NOTE: Numbers in brackets refer to the number of samples that were averaged.

2) the contact between units III and II was taken to be the top of the usually thick lacustrine deposits of fine sand, silt or clay in the Interstadial Drift; in the middle part of the basin this contact is highly interpretive;
3) the contact between units II and I was taken to be the base of the Halton Till in the Upper Drift; this contact is often difficult to determine precisely because at many locations the Halton Till directly overlies tills in the Middle Drift unit.

The Lower Drift consists wholly of till that may be equivalent to the (Illinoian) York Till described by Karrow (1967) in the Scarborough area. Samples of the till obtained through test drilling indicate the till to be compact with an abundance of shale fragments in a sandy matrix (Table 3). Seven samples of the till had an average composition of 14% clay, 20% silt and 66% sand, and an average calcite/dolomite ratio of 4.6. The sand till was present in five test holes (4710, 10548, 4885, 6003, 6004) and in each was found directly on top of the shale bedrock. At the four locations south of the Oak Ridges Moraine, the till is less than 15 feet thick, but in test hole 4885 on the Oak Ridges, the shaly till was found to have a total thickness of 80 feet.

The Interstadial Drift consists largely of thick, continuous deposits of lacustrine or deltaic sands, silts and clays tentatively correlated to the Scarborough and the Thorncliffe formations described by Karrow. At some localities these two formations are separated by a till possibly equivalent to the Sunnybrook Till. However in most areas of the basin, the till is missing and the two sequences of lacustrine deposits merge into one thick unit that in places exceeds 200 feet. In many areas of the basin these deposits contain the main permeable water-bearing formations at depth, and in the area of the Markham and Unionville aquifer systems, these sands form a complex of permeable deposits with overlying kame sands and gravels found in the Middle Drift unit.

The Sunnybrook Till correlative was found in only four of the 19 test holes; test holes 10548, 12295, 12294, and 4709. The thickest section of the till occurred in test hole 12295 where it was identified to be 40 feet. At each location the till was a dense clay or silt till, and the grain-size analysis of four samples indicated an average composition of 36% clay, 42% silt and 22% sand. The average calcite/dolomite ratio for the four samples was 2.4. Pebble counts were available for only two samples; in test hole 12295 no pebbles were found, and in test hole 12294 there were only 5, all shale.

The Middle Drift consists primarily of tills with thin interstratified deposits of sands, silts and clays. Significant deposits of ice-contact sands and gravels in the middle parts of the basin have also been placed in this unit. The tills are tentatively equated with the time of deposition of the Meadowcliffe and the Seminary tills in the Scarborough area. The sands, silts and clays represent deposition in local pondings or lakes during fluctuations of the ice front in the area. The ice-contact deposits are probably associated with these same fluctuations.

The composition of the tills is variable, ranging from a clay, to a silt, to a sand till in different areas and at different depths. The average composition of 27 samples was found to be 27% clay, 40% silt and 33% sand, with an average calcite/dolomite ratio of 3.2. Limestone pebbles were most common, with only minor amounts of crystalline, dolomite

and shale pebbles present. Till thicknesses in the order 30-40 feet are common.

The waterlaid deposits of the Middle Drift unit are predominantly interbedded silts and clays with only minor beds of fine sand. The total sequence is usually less than 20 feet thick.

Buried kame or ice-contact sands and gravels have been identified in test holes 10256, 12293, 6006 and 5831. The gravels were found to be very coarse in all four test holes and the lateral continuity of the deposits is highly interpretive. However, the sands and gravels are a major aquifer unit in the basin and are closely associated with the Markham and Unionville aquifer systems. It is likely that the gravels in these aquifers occur as individual buried deposits in an otherwise continuous fluvial/lacustrine environment of sand and gravel. The underlying fluvial/lacustrine deposits may be associated with kame deposits of the Middle Drift unit and/or belong to the thick sequences of lacustrine deposits in the Interstadial Drift.

The Upper Drift unit consists mainly of the Halton Till with minor interbedded formations of sand and/or gravel. At some locations (test holes 6005, 5831, 12294, 6003), the till is very stony or grades vertically into poorly sorted "dirty" gravels. These complexes of (stony) till and gravel are thought to be the result of erosion of the till surface by water and/or the deposition of "waterlaid" till in ice-marginal ponds or lakes in front of a fluctuating ice margin.

The Halton Till is a compact silty sand till at most locations. The average grain-size composition of 43 samples obtained at different depths consisted of 22% clay, 33% silt and 45% sand. The average calcite/dolomite ratio for 40 samples was 5.3. As in tills in the Middle Drift unit, limestone pebbles were found to be most abundant, with small amounts of crystalline, dolomite and shale in the 38 analysed samples.

Although the Halton Till was found to exceed 100 feet in thickness in a number of test holes, more common thicknesses range between 50 to 100 feet in most areas in the watershed. On top of the Oak Ridges Moraine and south of the Lake Iroquois shoreline, the till is considerably thinner, being at most locations only 10 to 20 feet thick.

Deposits of sand and gravel in the Oak Ridges are part of the Upper Drift unit and occur between two sheets of the Halton Till. The deposits are very thick in the vicinity of the northern boundary of the basin, where approximately 244 feet of continuous sands and gravels were found in test hole 4885. The deposits pinch out towards the south and their southern extent is indicated by the southern boundary of the "Oak Ridges Aquifer" on Map 7.

HYDROGEOLOGY

GENERAL

Domestic water-supply requirements of rural and municipal systems in the basin are presently satisfied almost exclusively by ground water. Accordingly, population increases in the basin, especially in urban settings, has increased the development of ground water to the point that future urbanization must consider surface sources to meet anticipated demands. This problem does not commonly apply to rural domestic requirements.

To determine the full potential of future development and utilization of ground water in the watershed, an inventory of the resource is essential. This inventory has been carried out with the specific purpose of identifying the location and extent of the most major aquifers systems in the basin, and estimating the amounts of water available from each of the systems.

Although the inventory considers both bedrock and overburden sources, yields from bedrock are small and the discussions centre mainly around the major overburden sources. The overburden aquifer systems are described in terms of the physical and hydrologic parameters that distinquish each system, and estimates of yields from each system indicate its potential as a source of water supply. These estimates are approximations that reflect orders of magnitude and are not meant as definitive statements on the availability of water for the large range of possible uses at specific sites in the watershed. The local availability of water can be determined only through detailed test drilling, which should be undertaken whenever large quantities of water are sought. However, the quantitative estimates can be used to direct the conservation and use of ground water in areas where ground water is to be an essential factor in future land use development.

DATA BASE

Hydrogeologic data in the basin have been obtained from a variety of sources, the main ones being:

1) water-well records,
2) published geologic reports,
3) Ministry test drilling,
4) observation-well records,
5) geologic field mapping, and
6) ground-water studies associated with the Toronto Area Airport Project (TAAP) and the North Pickering Project (NPP).

The basic sources of information on hydrogeology in the basin consist of the water-well records submitted to the Ministry by all licensed water-well drillers in the Province. As of December 1974, there were approximately 3400 records for the basin and these provided information on the overburden and bedrock materials, depths to water levels and water-bearing zones, details of well construction, and short-term pumping test data. The locations of water wells throughout the basin are shown on Map 6 and a sample copy of the water-well record form is included in Appendix C.

The continuity and extent of permeable water-bearing formations in

the watershed are based largely on geologic information available from existing publications. Six publications were found to be especially useful and applicable: Karrow (1967, 1970), Dreimanis and Terasmae (1958), Watt (1957), Hewitt (1969), and Hewitt and Karrow (1963). These publications have provided information on subsurface lithology, stratigraphy, and relative ages of geologic materials, and have suggested the possible extent and continuity of overburden formations in the region. Formal stratigraphic names of major formations, as defined by Karrow (1967) and already discussed in the Geology chapter, are used whenever possible to facilitate discussions of overburden formations throughout the basin.

Hydrogeologic data obtained from existing water-well records were supplemented by precise lithologic logs obtained through an extensive test-drilling program carried out by the Ministry in 1970, 1971 and 1974. The subsurface data gathered through this program formed the basis for correlating the extent and continuity of overburden stratigraphy in the basin, and subsequently aided in determining the location, extent and continuity of aquifer materials referred to in the existing water-well records.

Water-level discussions are based on data gathered since late 1970 and early 1971 at nine different observation-well sites in the basin (Map 2). Data at three additional sites (wells 405, 406 and 512) are only short-term and are not discussed at this time.

A field reconnaissance survey of surface and near-surface geology was carried out during 1970 and 1971, during which time notes were also made regarding the locations of flowing wells, major seeps and springs, and other surface phenomena needed to understand the hydrogeologic regimes in the basin.

Ground-water studies associated with TAAP and NPP provided additional data on subsurface geologic stratigraphy, ground-water occurrence and aquifer parameters at specific sites in each project area. Data from the Toronto Area Airport Project (TAAP) and the North Pickering Project (NPP) studies became available during the latter stages of data analysis in 1975. However, none of these data are reproduced in this report because they are documented in associated publications listed in the Selected Bibliography.

OBSERVATION-WELL NETWORK

As of January 1976, there were 16 operational observation wells at 9 sites in the basin (some sites contain more than one well). The locations of all these sites are shown in Map 2 and the history of each well is shown in the accompanying table. Also included on the map and the table are 4 additional wells whose records do not extend into 1976 (wells 303, 304, 306 and 308).

There are two basic types of observation wells in the network:

1. abandoned domestic wells, which were instrumented with continuous water-level recorders, and
2. wells that were drilled during the preliminary study period in 1970 and 1974 and were subsequently constructed as manually measured 2-inch diameter piezometers, or as 6-inch diameter wells equipped with continuous water-level recorders.

The oldest observation well in the basin is well 106, which was constructed in 1963 to monitor the water level adjacent to the Don Mills municipal wells #1, #2 and #3.

Wells 301 to 306 (six wells) are abandoned domestic wells and their water-level records extend back to June of 1970. Subsequent to these, all observation wells in the network were drilled and constructed by the Ministry in association with its test-drilling programs. Wells 308 to 339 (ten wells) were constructed late in 1970, and wells 405, 406 and 512 were drilled in 1974.

Seven of the 20 wells indicate water-table fluctuations and have provided continuous water-level data for variable periods of time (wells 301, 302, 303, 305, 306, 308 and 329). The remaining 13 wells indicate fluctuations of piezometric levels at various depths in the overburden; eight of the wells are 2-inch piezometers that are measured manually and five wells are 6 to 8 inches in diameter and are equipped with water-level recorders that provide continuous records (see table on Map 2).

GROUND WATER IN BEDROCK

There are approximately 250 wells in the basin that have been drilled into bedrock, but only about 25 per cent of these have reportedly obtained water of useable quantity for domestic purposes. The other 75 per cent are reported as either "dry" and/or containing poor quality water and consequently not usable as sources for domestic supplies.

Two areas in the basin have a large concentration of bedrock wells (Map 6):

1. near Unionville, in the Regional Municipality of York, and
2. west-southwest of Ajax in the Regional Municipality of Durham.

Most bedrock wells around Unionville have been drilled as test wells for municipal supplies to explore the total thickness of overburden in the area. In almost all cases, water was reportedly found in the overburden rather than in the bedrock, and estimates of specific capacities of wells and transmissibilities in the shale were not made. Near Ajax, a large percentage of the wells have been drilled to bedrock because water-bearing zones were not encountered in the generally thin overburden. Twenty-eight bedrock wells in the area have sufficient data to allow the calculation of specific capacities which range between 0.005 and 0.7 gallons per minute per foot of drawdown. The median value is 0.05 gpm per foot. Transmissibility values were calculated on the basis of domestic well data and according to the method described by Ogden (1965). These range between 5 and 1200 gpd per foot, with a median value of 60 gpd per foot.

As evident from these statistics, the shale bedrock has low transmissibilities and consequently yields only small quantities of water to domestic wells. Yields (as noted by water-well contractors) from the wells are usually in the order of 1 gpm and seldom exceed 3 gpm. Supplies of these quantities are usually marginal for domestic uses and would not be adequate to meet large requirements.

Natural gas is a common occurrence in many wells in shale, together with reported occurrences of salty and sulphurous water in some wells (see Map 13). These quality problems are an added deterrent to seeking ground water from the bedrock.

Most bedrock wells in the basin end in shale and are not drilled

through the total thickness of shale to explore the underlying limestones of the Trenton Formation. Consequently, the occurrences of ground water in the deeper shale and limestone formations are not known. However, it is expected that the shale is a poor water-bearing unit throughout its thickness. The underlying limestones of the Trenton Formation are known to be a poor source of ground water east of the watershed, and this probably applies to the formation in the basin. Therefore, the exploration for water in either the shale or the limestone bedrock is generally not recommended.

GROUND WATER IN OVERBURDEN

Overburden aquifers are the primary sources of water for rural domestic and municipal supplies in the basin. While most aquifers yield sufficient quantities for domestic uses, larger supplies necessary for municipal and large-scale irrigation projects are possible in only certain parts of the watershed. Locating these high-capacity areas involves extensive data gathering and evaluation. The present study is designed to consolidate all physical and hydraulic data available from about 3400 water-well records in the basin, and to delineate the major individual aquifers or aquifer systems in order to provide a rational data base for future ground-water exploration and development.

The major aquifer systems are indicated on maps 7 and 8 and are identified on cross sections shown in Figure 3. Each aquifer system represents, for the most part, a continuous permeable geologic deposit from which wells obtain quantities of water sufficient for the intended uses. These aquifer systems and their continuity and extent have been identified on the basis of the similarity of geologic materials and context, similar elevations of the top of each aquifer, and a consideration of the elevations of static water levels in completed wells in each aquifer. Formations with approximately similar elevations and static levels were interpreted to be part of a continuous aquifer system. The approximate elevation of the top of each aquifer system is shown in brackets after its name.

It should be noted that the interpretations of aquifers based on similarity of elevations sometimes necessitate a liberal degree of judgement regarding the extent and continuity of permeable geologic deposits. It is recognized that at times this judgement is made with little data in some areas and consequently, the aquifer interpretations presented in this report should be considered tentative and subject to modifications as new or more exact hydrogeologic data become available.

To simplify the presentation of overlying aquifers, the aquifers are shown on two separate map sheets. Aquifers in the "upper" aquifer system generally overlie those in the "lower" system. In areas where there is only one system, the system is shown on the upper aquifer map (Map 7).

Each aquifer system represents an area in which water can usually be obtained at depths similar to those indicated on the maps. However, in some of the larger systems such as the lower Markham and Greenwood aquifer systems, the deposits may have variable grain-size distribution both horizontally and vertically, and the deposits may not be permeable at depths similar to those shown on the maps. In these cases, ground water may be obtained from variable depths in the aquifer systems, or from other undefined aquifers in the area.

There are areas in the basin where it has not been possible to identify discreet aquifer systems. The continuity and extent of deposits in these areas could not be identified reliably either because of insufficient data to interpret their extent, or because of the complexity of the local lithology. Existing wells in these areas usually obtain water from local lenses of sand and gravel at varying depths. Often shallow dug wells in poorly-permeable materials yield enough water for conservative domestic uses.

Fourteen aquifer systems in the basin have been identified and named:

1. Oak Ridges
2. upper Markham
3. lower Markham
4. upper Unionville
5. lower Unionville
6. upper Victoria
7. lower Victoria
8. upper Brougham
9. lower Brougham
10. Greenwood
11. Atha
12 Green River
13. Pickering
14. Cedar Grove

No attempts have been made to incorporate into the present report the locations and extent of the permeable formations identified by Ostry (in preparation) in the lower part of the Duffins Creek area, or those mapped by Morrison (1976) on the NPP site. It is felt that the fine detail of mapping carried out by both Ostry and Morrison is not fully compatible with the scale of data interpretations presented in this report in which only large-scale aquifers have been mapped.

Each of the 14 aquifer systems have characteristic physical and hydraulic properties that distinguish them from adjacent ones. These characteristics are summarized in tables on maps 7 and 8. The physical characteristics shown in the tables have been collated from water-well records filed with the Ministry. However, only limited data are available on aquifer coefficients of transmissibility and storage. The coefficient of transmissibility (T) was calculated for only those domestic wells that have a specific capacity greater than 1 gpm/ft, and for wells with long-term pumping tests, i.e., mainly municipal wells. The method of calculating T for domestic wells is described by Ogden (1965). These formulae are given in Appendix D. For this calculation, the coefficient of storage for confined aquifers was assumed to be $5x10^{-4}$, and 0.1 for water-table aquifers. The Hantush (1964) leakage formula was used where a non-steady state flow was indicated from associated observation-well data; otherwise the Jacob (1953) simplified formula was applied (Appendix D). Where possible, the coefficients of leakage (L) were also calculated using the Hantush formulae.

The three coefficients (T,S,L) are presented (on the maps) primarily for general information since discussion of the significance of these values is beyond the present scope of the report.

The specific capacity of a well represents the amount of water

available from that well, per foot of water (or available drawdown) in the well. The value is not constant but varies with factors such as the degree of penetration of the aquifer, clogging of the well screen, well development, and the caving of the aquifer material around the well screen. All these factors tend to reduce the efficiency of a well and therefore its specific capacity.

The calculated specific capacities shown on maps 9 and 10 relate to the estimated probable well yields for each of the aquifer systems. The higher the specific capacity, the higher the probable yield. However, the relationship is not constant and there can be large variations. Consequently, the indicated values should be used for comparitive purposes only rather than for estimating yields of new wells. The probable well yields shown on the maps have been based partly on specific capacity values, with the additional factors of geologic material, thickness of aquifer penetration, type of well, etc. being considered collectively.

The Oak Ridges Aquifer System

The largest complex of closely associated aquifers in the basin is referred to as the Oak Ridges aquifer system. The system is located in a broad east-west belt in the northern part of the watershed (Map 7) where it coincides closely with the physical outline of the Oak Ridges Moraine. It has a surface area of approximately 86 square miles. Aquifers in the unit consist of fluvial sands and gravels of variable extent, continuity and thickness. The thickest saturated deposits occur in the northern and eastern parts of the basin where thicknesses commonly exceed 100 feet; these deposits get progressively thinner and pinch out completely towards the south. The average saturated thickness of the total system is about 50 feet.

Most of the uppermost aquifers in the system are unconfined, with water-table depths ranging from about 20 to 50 feet below ground surface. Piezometric surface depths in the deeper confined aquifers range from 0 (flowing wells) to approximately 130 feet. A number of deep wells in the northeastern part of the aquifer have piezometric surface depths in excess of 200 feet. However, static depths of this magnitude are rare.

The water-level contours in shallow wells on the Oak Ridges (Map 11) indicate a gradual water-level slope towards the south. The upper stretches of Bruce Creek and Duffins Creek are two streams that significantly influence the configuration of shallow water levels. Both streams receive ground-water discharge from unconfined aquifers in the unit and this discharge is probably significant in providing surface runoff to the headwater stretches of Bruce Creek north of Gormley and to Duffins Creek and its headwater tributaries northeast of Claremont.

The confined aquifers of the Oak Ridges system west of Stouffville have piezometric surface elevations above ground and consequently most wells in the area flow (Map 14). Static water levels in most of these wells are less than 5 feet above ground level and therefore the individual flows are small. However, since there are approximately 130 flowing wells in the area, the total ground water released to surface drainage is significant. In fact, streams in the area consist almost wholly of ground water released from flowing wells, and this places a special importance on ground-water discharge in the area. In all pro-

bability, if the flowing wells did not exist, neither would many of the small headwater streams during dry summer months.

It is a popular belief that the Oak Ridges Moraine is a significant ground-water "recharge" area that should be protected from future urban-related land development. This concept places obvious constraints on future development in the area that cannot be justified on the "recharge" theory. On the contrary, much of the Oak Ridges area is covered by poorly permeable till on the surface, which allows little local infiltration of precipitation. Significant quantities of precipitation infiltrate only where the till cover is very thin (<5') and where sands and gravels outcrop. Consequently, it is only these areas that can be labelled as significant "recharge" areas in which carefully planned land development must be exercised. Development on surface till areas on the moraine is a viable concept that would probably not endanger ground-water quantity or quality significantly. Therefore, the concept of "recharge" should not be applied categorically to all of the Oak Ridges Moraine area. Rather, it should be recognized that there are certain high infiltration areas on the Oak Ridges in which ground water is rapidly replenished by precipitation. It is primarily the Oak Ridges aquifer system that benefits directly from this replenishment. It may not be reasonable to expect that distant aquifers such as the Unionville aquifer systems obtain any direct benefit from this recharge. The Victoria and Markham aquifer systems likely receive some leakage from the Oak Ridges aquifers, but because of the large sizes of these southerly system, local recharge through vertically downward flow to the aquifers can likely be considered more significant. However, it is indisputable that water in the Oak Ridges aquifer system provides a head drive to all ground water adjacent to it (north and south).

Individual well yields in the Oak Ridges aquifer system are variable, depending on the location of the well and the particular permeable zone it penetrates. Wells located in the eastern parts of the Oak Ridges physiographic region will have generally higher yields because the individual aquifers in the system contain thick saturated deposits of sands and gravels, while in the western parts of the region less permeable sands are the more dominant aquifer materials. Domestic supplies (up to 10 gpm) are readily obtainable from all drilled wells within the Oak Ridges aquifer complex and most wells should yield 50 gpm and more. Larger quantities of water for municipal and irrigation uses are available and it is estimated that in many areas yields in excess of 100 gpm are possible. For example, Oak Ridges municipal wells #1 and #2 have capacities of 170 and 300 gpm, respectively, and Stouffville wells #5 and #8 are rated at 700 and 350 gpm, respectively.

Specific well capacities in the Oak Ridges aquifer complex vary over a large range. The maximum of 53 gpm/ft is the capacity calculated for Stouffville municipal well #5, but many values for domestic wells are less than 0.1 gpm/ft. At a value of 0.1 gpm/ft, a domestic well would have to have a minimum of 20-30 feet of water in the well to provide adequate supplies for domestic uses. With less water in the well, the pumping would have to be regulated during continuous demands to avoid the well going temporarily "dry".

The Upper and Lower Markham Aquifer Systems

The upper and lower Markham aquifer systems are located near the centre of the basin between Markham and Stouffville (maps 7 and 8). The

two systems are superimposed on top of each other directly north of Markham, but the lower aquifer is larger in total area and extends across the eastern boundary of the Regional Municipality of York into the Durham region.

The upper aquifer system is assumed to be part of a system of kame and glacio-fluvial deposits in the Middle Drift unit, and the extensive sands found in the lower system probably belong mainly to the Interstadial Drift unit. This complex of Middle Drift and Interstadial Drift deposits predominates in the area and is indicated in Figure 2 in the area of test holes 10253, 10254 and 10256. Very coarse gravels in the upper aquifer were encountered in test wells 10253, 10256 and 4127 (see well logs in Appendix A). In the latter two wells the drilling had to be terminated in the coarse gravels because the drilling equipment was not adequate to penetrate the coarse deposits. The average thickness of continuous sand and/or gravel in each aquifer is approximately 30 feet.

The separation of the upper and lower aquifers has been based mainly on differences in the elevation of the top of the aquifers (at which water is usually located). Since there is little difference in static water levels in the two aquifers systems, a good hydraulic continuity exists between the two aquifers. It is suspected that at some locations the two systems form essentially a continuous aquifer unit.

The elevation of the top of the upper aquifer system ranges from 550 feet to 615, with a mean of 580 feet. In contrast, the top of the lower aquifer system ranges in elevation from 474 to 555 feet, with a mean elevation of 540 feet. Average depth to top of the upper system is about 120 feet, while the top of the lower system is found at an average depth of 160 feet.

Both aquifers are confined and the depths of static water levels vary from flowing (0 depth) in both systems to 130 feet deep in the upper aquifer and 90 feet in the lower. Average water-level depths are in the order of 20-30 feet. Flowing wells in both aquifers have been encountered mostly adjacent to Little Rouge Creek north and northeast of Markham.

Individual specific well capacities in domestic wells in the two aquifers are variable and the probable potential yields to wells range from 10 gpm to 50 gpm (maps 9, 10). These yields are more than adequate for domestic needs and are sufficient to satisfy small-scale irrigation and municipal demands. Potential yields greater than 50 gpm exist over a large area in the upper system and in several small areas in the lower system. These areas contain primarily coarse sand and gravel. Mainly sand is found in areas where the potential yields are estimated to be 10-25 gpm and 25-50 gpm. One Markham municipal well is in the lower system and the other is in the upper one, and both are rated at a potential capacity of 1000 gpm. However, only a few wells could be developed to this capacity in either of the aquifers without significant water-level lowerings occurring locally.

The Upper and Lower Unionville Aquifer Systems

The upper and lower Unionville aquifer systems are almost identical in shape and are centered roughly under Unionville just west of Markham. The two systems are part of the Middle Drift-Interstadial Drift complex that occurs in the area. Sand is the predominant material in each

system, but very coarse sand and/or gravel can be found locally. Average saturated thicknesses of aquifer materials in both systems are about 20 feet and most domestic wells penetrate only about 5 to 10 feet into each aquifer to obtain the required supplies.

The differences in elevations of the tops of the two aquifer systems vary between 50-100 feet. The mean elevation of the top of the upper aquifer is about 550 feet and the top of the lower aquifer is at about 480 feet.

At most locations there are only slight differences between the elevations of static water levels in wells in the two system; the difference is usually less than 10 feet, with water levels in the lower aquifer unit being generally lower (maps 7, 8). In the flowing well area (shown on Map 14) where the wells flow from both aquifers, the piezometric surface in the lower aquifer is slightly higher than in the upper aquifer zone, indicating an upward component of ground-water movement.

Existing data indicate probable well yields in the 25-50 gpm range in most areas in the upper system and 20-25 gpm throughout most of the lower unit. Yields in excess of 50 gpm in each system are possible, as indicated by two Unionville and a total of seven Thornhill municipal wells (outside basin) in the lower system, and one Unionville municipal well in the upper unit. The yields for these wells vary from 150 to 700 gpm, which is an indication of local potential yields in the two systems. However, past interference with water levels in nearby domestic wells suggests that the 700 gpm value is probably too high to be considered a safe sustained yield without appreciable drawdown of the piezometric surface and possibly the eventual local dewatering of the aquifer. The 350 gpm indicated for each of the Don Mills (Thornhill) #1 and #2 wells in the lower Unionville aquifer is probably a realistic value in the area.

The Upper and Lower Victoria Aquifer Systems

The upper and lower Victoria aquifer systems are located northeast of Richmond Hill in the vicinity of Victoria Square in the Rouge River sub-basin. The northern boundary of the upper aquifer system underlies a small part of the Oak Ridges aquifer, while deposits in the lower aquifer are located much deeper and extend farther north under the southern part of Oak Ridges Moraine.

Both systems are primarily in the Middle Drift unit where fine to coarse sand is the most common permeable material in the area. Occasional occurrences of gravel have also been noted. Average saturated thicknesses of sand in either aquifer are small, with an estimated average thickness of 15 feet in the upper aquifer and only 10 feet in the lower unit. Most wells in either aquifer usually penetrate less than 10 feet of sand to obtain domestic supplies.

The elevation of the top of the upper Victoria aquifer system ranges from 637 to 740 feet, with a mean value of 680 feet, and the elevations in the lower system range from 545 (a singularly low value) to 644 feet, with a mean of 600 feet. Average depths to the tops of the upper and lower systems are 70 and 150 feet, respectively.

Water-level elevations in wells in the two aquifers are similar, with water levels in the lower aquifer being generally higher than those

in the upper system. Elevations in the upper aquifer range from 702 to 798 feet, and in the lower aquifer from 710 to 792 feet. These elevations correspond to average water-level depths of approximately 20 feet in wells in each system. In the southern portions of the lower aquifer, some water levels are above ground surface and this results in flowing wells. The flowing wells are especially evident in topographically low areas such as in the vicinity of Bruce Creek and other small streams in the area (Map 14). A few wells in the upper aquifer in the vicinity of Bruce Creek also flow.

Potential well yields in the lower aquifer system are generally much higher than in the upper system. Whereas most of the upper system has potential yields of 2-10 gpm, yields over the majority of the lower system fall in the two ranges of 10-25 and 25-50 gpm. More than 50 gpm is probable from wells in two separate areas indicated on Map 10. In both of these areas the formation consists mainly of sand and gravel in an otherwise predominantly sand aquifer.

The Upper and Lower Brougham Aquifer Systems

These two aquifer systems are in the Duffins Creek basin in the vicinity of the Brougham. The lower system has a surface area of approximately 12 square miles and the upper has an area of approximately 8 square miles.

Both systems consist mainly of fine to medium sand, with the upper aquifer being part of a regional lacustrine deposit within the Middle Drift, and the lower aquifer located in a sequence of Thorncliffe sands found in the Interstadial Drift. The two systems are separated by approximately 110 feet of silt, clay and till, with the elevation of the top of the upper aquifer at approximately 640 and the lower at 530 feet. The upper system has an average thickness of 20 feet of water-bearing sands, while the lower system contains an average of only 10 feet of permeable sands.

Both aquifer systems are relatively deep. The total range of depths for the upper system is 20-191 feet, with an average depth of 120 feet; the range of depths for the lower system is 14-283 feet, with an average depth of 110 feet. For each system, the shallower depths occur in the valley of Duffins Creek where both aquifers are cut partially by the valley. This leads to considerable ground-water discharge from each aquifer into Duffins Creek.

The piezometric surface configuration in both systems shows a dip toward the south-southeast, with Duffins Creek having a pronounced effect on the configuration in the lower aquifer. In areas of overlap of the two systems, the water level in the upper aquifer is approximately 40 feet higher (in elevation) than in the lower aquifer. Only one well in the lower aquifer (in the valley of Duffins Creek) flows, while none of the wells in the upper system flow.

Expected well yields from each aquifer are in the order of 10-25 gpm. However within this range, individual well yields in each system are variable. Most domestic wells are usually inefficient and will yield small quantities of water (3-5 gpm), while a properly screened well of 5 inches in diameter or larger that is developed for high capacity should readily yield higher quantities of water.

The Greenwood Aquifer System

The Greenwood aquifer system is located in the central part of the Duffins Creek basin and the northern portion of it underlies the Brougham lower aquifer. The top of the Greenwood aquifer is at an approximate elevation of 440 feet and is the lowest significant overburden aquifer system identified in the area.

The aquifer system consists mainly of fine to coarse sands with gravels reported in some wells. These materials belong to the Interstadial Drift unit of lacustrine sands and associated with fluvial, coarse-grained deposits. In MOE test hole 4709 the sands varied from medium to coarse with lenses of gravel, while in test hole 6003 the sands were primarily fine- to medium-grained with no associated gravels. Materials directly overlying the aquifer consist of either fine-grained lacustrine sand, silt and clay (as in test hole 4709), or till (as in test hole 6003).

The average thickness of the permeable portion of the deposit is approximately 20 feet, although most domestic wells penetrate less than this thickness.

Depths to the top of the aquifer vary from 5 to 421 feet, with an average of 130 feet. The aquifer was encountered at a depth of 148 feet in test hole 4709 and at a depth of 170 feet in test hole 6003. The shallower depths occur generally in the southern parts of the aquifer where the land elevation is lower, and in the valley of Duffins Creek which is cut partly into the aquifer.

The piezometric surface in the vicinity of Duffins Creek in the eastern part of the aquifer dips eastward towards the stream valley, while in the southwestern part of the aquifer the dip is southeast. Only one well in the aquifer flows, although a number of wells in the vicinity of the valley of Duffins Creek have high (shallow depth) static water levels. Average static water-level depth is approximately 55 feet below ground surface.

The estimated probable yields to wells in the aquifer are approximately 10-25 gpm, although higher yields are possible from local gravelly portions in the northern parts of the aquifer. These gravels appear to be generally thin and it is highly unlikely that any one well can be developed to exceed 100 gpm because the available drawdowns are small.

Atha, Green River, Pickering and Cedar Grove Aquifer Systems

Each of these aquifers is of relatively small importance and only a brief description of the important features of each is presented. Each system covers an area of less than 10 square miles and the water-bearing zones in each are probably significant only locally. The Atha system is part of the Upper Drift unit, the Green River is probably in the Middle Drift unit, and the Pickering and Cedar Grove systems are located in the upper part of the Interstadial Drift unit.

Ground water in the Atha aquifer is obtained from shallow,local lenses of sand and/or gravel less than 50 feet deep in the Halton Till. Very often the gravel-like material represents a modified (washed) till from which some of the fines have been washed out. However because of poor sorting, the remaining gravel-like material has generally a low permeability and individual well yields are sufficient to satisfy mainly domestic requirements. The average thickness of individual sand

and gravel lenses is approximately 10 feet. In places where the gravels represent washed till, the thickness of well-sorted, permeable materials is less.

The Green River and Pickering aquifer systems consist primarily of sands found in their respective drift units. Sands in the Pickering system are generally coarse and often interbedded with gravels. The deposits have an average thickness of about 10 feet near the top of the unit, but greater thicknesses may be encountered in wells drilled deeper into the unit. Most wells in the Green River aquifer system encounter water at an approximate depth of 100 feet, and in the Pickering system at about 30 feet.

The Cedar Grove aquifer is found in the upper part of the Interstadial Drift unit and may be a continuation of the Greenwood aquifer to the northeast. The aquifer material consists of sand and/or gravel approximately 20 feet thick, with existing domestic wells in the aquifer penetrating an average of 5 feet into the aquifer to obtain sufficient supplies of water. The average depth to the top of the formation is approximately 80 feet.

Probable well yields from the Pickering and Cedar Grove aquifers can be expected to range from 10-25 gpm in the coarse sand and gravel portions of each aquifer, while yields in the Atha and Green River systems can commonly range from 2-10 gpm. Expected yields from all the aquifers are sufficient to satisfy domestic requirements, but substantially larger yields may be difficult to obtain.

GROUND-WATER MOVEMENT

Ground-water movement is a three-dimensional process that involves complex inter-relationships among the occurrences and permeabilities of geologic materials, hydraulic gradients, and ground-water recharge and discharge phenomena. These inter-relationships are variable throughout the basin and consequently produce intricate and complex ground-water movement patterns that are difficult to assess and describe accurately.

For simplicity, ground-water movement in the watershed is presented 1) in the horizontal plane in shallow systems by the configuration of the water-level contours on Map 11, and 2) in both horizontal and vertical planes in the deeper confined aquifer systems delineated on maps 7 and 8. The estimated quantities of steady, horizontal ground-water movement in each of the confined aquifer systems is shown in Table 4, and the quantities of vertical flow downward into each aquifer is given in Table 5. Assuming that recharge vertically upward towards each aquifer is negligible, the downward flow represents the main source of recharge to each system.

Horizontal Component

The horizontal component of ground-water movement in shallow systems (Map 11) is generally southward from the Oak Ridges Moraine towards Lake Ontario. Locally, the movement is towards major streams, with Duffins Creek, West Duffins Creek, Rouge River and Little Rouge Creek being major discharge areas for shallow ground water.

The horizontal components of flow in deeper aquifer systems shown on maps 7 and 8 conform to the southward flow pattern dominant in shallow systems, and the major streams again influence piezometric surfaces in the underlying aquifers. The effects of Duffins Creek on piezometric

surfaces in the Greenwood and the lower Brougham aquifer systems is pronounced, resulting in a significant quantity of ground water flowing into Duffins Creek from these aquifers (Table 7). The horizontal component of ground-water flow in both of these aquifers amounts to approximately 0.4 mgd (0.8 cfs) towards Duffins Creek (Table 4).

The average flow of 4.5 mgd in the Oak Ridges aquifer is assumed to represent the horizontal component of (unconfined) flow over the total area of 86 square miles of the complex.

Vertical Component

The vertical component of ground-water movement has been determined only for areas overlying the aquifer systems shown on maps 7 and 8. This investigation has involved the determination of upward or downward movement of water in saturated areas above each aquifer, and the quantification of downward movement of water towards each aquifer (Table 5). These quantities represent the main component of recharge of water to each aquifer.

The vertical direction of movement was determined by comparing the elevations of water levels in shallow ground water shown on Map 11, to the elevations of the piezometric surfaces in the aquifers shown on maps 7 and 8. The results are indicated in figures 4 and 5. Downward movement of water occurs generally in areas where the elevation of water levels in shallow ground water is higher than the piezometric surface elevation in the underlying aquifers, and an upward component results in areas where the water level in shallow ground water is lower.

Each of the major identified aquifer systems are overlain by areas of both upward and downward flow. Areas of upward flow occur in topographically low areas such as stream valleys, and areas of downward flow are coincident with topographically high areas of land. The valleys associated with Duffins Creek, Rouge River and their major tributaries are all areas of upward movement from the deep aquifer systems. The large area of upward flow in the Oak Ridges Moraine incorporates the Stouffville flowing well area. Most of the other areas of upward flow also contain flowing wells.

Areas of downward flow over confined aquifers represent locations where ground water percolates into the deeper confined systems. In the unconfined portions of the Oak Ridges aquifer, the direction of ground-water movement is assumed to be downward.

Based on leakage values shown in the tables on map 7 and 8, the average value for materials overlying all aquifers was assumed to be 3×10^{-4} gpd/ft^3. The quantity of flow was based on the equation:

$$Q = 27.87\ LA\Delta h$$

where:
- Q = downward flow (mgd)
- L = coefficient of leakage (gpd/ft^3)
- A = surface area of downward flow (sq mi)
- Δh = head difference across confining bed (ft)

Estimates of downward flow towards the Pickering and Cedar Grove aquifers were not made because of the small areas of downward flow over

Table 4. Horizontal Component of Ground-Water Movement Within Each of the Major Aquifer Systems

Aquifer	Transmissibility, T (gpd/ft)	Average Gradient, I (ft/mi)	Approximate Width, b (mi)	Horizontal Flow, Q (mgd)
Oak Ridges	3800	63	19	4.5
Markham				
upper	3500	13	3.5	0.16
lower	2700	16	6.8	0.29
Unionville				
upper	2000	17	3.0	0.10
lower	3700	18	4.0	0.27
Victoria				
upper	1800	24	4.0	0.17
lower	2500	30	5.2	0.39
Brougham				
upper	1800	40	2.8	0.20
lower	1300	58	5.0	0.38
Greenwood	1500	54	5.0	0.41
Atha	500	40	3.7	0.07
Green River	1600	36	2.1	0.12
Pickering	1600	31	1.6	0.08
Cedar Grove	1600	30	1.5	0.07

$Q = TIb \times 10^{-6}$

Q = steady horizontal component of flow in aquifer (mgd)
T = transmissibility (gpd/ft)
I = gradient across aquifer (ft/mi)
b = width of aquifer perpendicular to direction of flow (mi)

Figure 4. Vertical direction of ground-water movement through materials overlying the upper aquifer systems in the overburden.

Figure 5. Vertical direction of ground-water movement through materials overlying the lower aquifer systems in the overburden.

Table 5. Vertically Downward Movement of Ground-Water to Each of the Major Aquifer Systems

Aquifer	Surface Area of Downward Movement,* (sq mi)	Average Head Difference, Δh (ft)	Leakage, L (gpd/ft^3)	Downward Flow, Q (mgd)
Oak Ridges[1]	86	-	-	17.2
Markham				
upper	11.3	20	$3x10^{-4}$	1.9
lower	4.7	30		1.1
Unionville				
upper	9.0	35		2.6
lower	3.0	15		0.4
Victoria				
upper	8.4	10		0.7
lower	2.4	15		0.3
Brougham				
upper	6.2	75		3.9
lower	2.0	50		0.8
Greenwood	11.0	50		4.6
Atha	5.3	15		0.6
Green River	2.8	15		0.4
			Total	34.5

*see figures 4 and 5

[1] for the purpose of estimating downward movement of water into the Oak Ridges aquifer, the system is assumed to be unconfined over its entire area of 86 square miles. Average infiltration over this area is assumed to be 0.2 mgd per square mile.

$$Q = 27.87\, LA\Delta h$$

Q = downward flow (mgd)
L = coefficient of leakage (gpd/ft^3)
A = surface area of downward movement over aquifer (sq mi)
Δh = head difference across confining bed (ft)

each aquifer. Estimates of flow into the Oak Ridges aquifer were made on the basis of an average surface infiltration rate of 0.2 mgd/square mile applied over the total surface area of 86 square miles.

The relatively large downward flows towards the Brougham and Greenwood aquifers are the result of large head differences created by the discharge of water from each aquifer into Duffins Creek. For the upper and lower Brougham aquifer systems, the 4.7 mgd combined flow (Table 5) corresponds to approximately 5.4 cfs discharged into Duffins Creek. To maintain this discharge, approximately 9 inches of precipitation would have to infiltrate over the 8.2 square mile area of the two systems. Following the same line of reasoning for the Greenwood aquifer, the 4.6 mgd downward flow corresponds to a discharge of 5.2 cfs into Duffins Creek. This is equivalent to 6.4 inches of precipitation added to ground water over 11 square miles of the aquifer.

WATER-LEVEL FLUCTUATIONS AND CHANGES IN STORAGE

There are abundant water-level data in the basin, with a total of 20 observation wells scattered throughout the watershed (Map 2). The water-level hydrographs for most of these wells are similar and representative trends are shown by fluctuations in nine wells indicated in Figure 6. The annual high and low levels prevalent on the hydrographs occur consistently in the spring and late summer months. The total range of fluctuations are also consistent in any one well from year to year, but vary with individual well locations and depths.

The average annual ranges of water-level fluctuations shown in Figure 6 have been used to estimate the average annual change in storage in unconfined ground water by use of the following equation:

$$\Delta S = 0.475\ AY\ \Delta h$$

where:

ΔS = average daily change in storage over 365 days (mgd)
A = surface area over which ΔS applies (sq mi)
Y = assumed specific yield of materials (on Map 5)
Δh = average annual range of water-level fluctuation (ft)

The results are shown in Table 6.

Observation well 301 was used to indicate the total range of fluctuations in unconfined sands and gravels primarily on the Oak Ridges Moraine; well 303 was used to indicate fluctuations in surficial lacustrine sands; well 305 was used to indicate water-level changes in the Halton Till, and well 308 was used to indicate fluctuations in silt and clay. At well 301, a thin deposit of till approximately three to four feet thick overlies sands and gravels, and approximately two feet of surface till is present at well 303.

Since about 1970 (the earliest water-level data in observation wells), the average annual change in ground-water storage has been assumed to be zero, but the changes in storage during any one year have averaged approximately 44.3 mgd (Table 6). What this signifies is that for the water level to recover from the annual low to the annual high, at least this much water had to be recharged to ground water through precipitation.

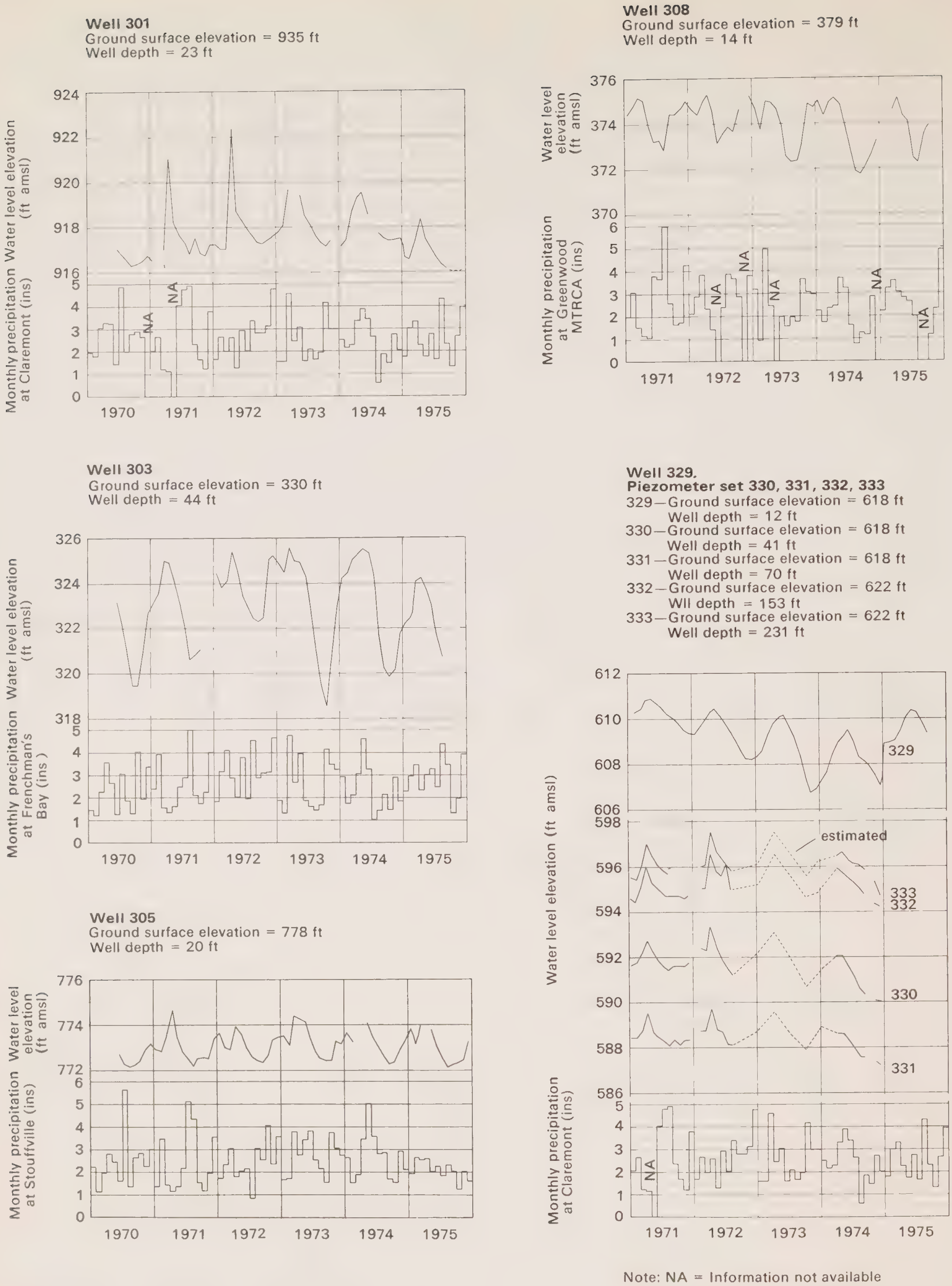


Figure 6. Water-level hydrographs of nine observation wells in the basin.

Table 6. Changes in Ground-Water Storage in Unconfined Formations

Surficial Deposit	Specific Yield, Y	Δh (ft)	Rouge River Area (sq mi)	Rouge River Δs (mgd)	Duffins Creek Area (sq mi)	Duffins Creek Δs (mgd)	Petticoat Creek and Others Area (sq mi)	Petticoat Creek and Others Δs (mgd)	Total Basin Area (sq mi)	Total Basin Δs (mgd)
Sand and Gravel	0.02	4	9	3.4	34	13.	2.0	0.76	45	17.2
Sand	0.2	5	8	3.8	9	4.3	4.7	2.2	21.7	10.3
Till	0.1	2	79.7	7.6	66.9	6.4	10.	0.1	156.6	14.1
Clay, Silt	0.05	2.5	33	2.0	10	0.59	2.2	0.13	45.2	2.68
Total			129.7	16.8	119.9	24.29	18.9	3.19	268.5	44.28

$$\Delta S = 0.475\ AY\Delta h$$

ΔS = average daily change in storage over 365 days (mgd)
A = surface area over which ΔS applies (sq mi)
Y = assumed specific yield of materials
Δh = average annual range of water-level fluctuation (ft)

Table 7. Ground-Water Discharge to Major Streams

Basin	Stream Gauge No.	Drainage Area (sq mi)	Period of Available Record (yrs)	Mean Streamflow (cfs)	Estimated Ground-Water Discharge		Ground-Water Discharge as % of Mean Streamflow (%)	Surficial Sand and Gravel Area as % of Drainage Area
					(cfs)	(mgd/sq mi)		
Little Rouge Creek	2HC028	30	64-70	22.8	7.4	0.133	32	6.6
	2HC014 (same loc. as 2HC104)	41	57-63	25.8	7.2	0.094	28	6.1
Rouge River	2HC022	72	62-70	47.4	13.	0.097	27	6.2
	2HC015 (same loc. as 2HC103)	86	57-61	47.2	14.	0.087	30	6.6
West Duffins Creek	2HC026	50	64-70	29.3	10.7	0.116	37	17.8
	2HC019	34	62-70	38.0	23.	0.365	61	30.0
Duffins Creek	2HC006	110	46-70	95.6	48.	0.234	50	22.0

GROUND-WATER DISCHARGE TO STREAMS

All streams in the basin receive ground-water discharge, most of which is obtained from shallow ground-water systems. In most cases this water is discharged directly into the stream through bank seepage, and the rate of seepage is closely associated with the permeability of surficial soils in the drainage area. In addition to discharge through bank seepage, flowing wells in the Stouffville area provide a significant proportion of streamflow to many of the headwater streams of Little Rouge Creek.

Total ground-water discharge into streams has been estimated on the basis of the method used by Bloyd (1975), which involves the construction of flow-duration curves for streamflow. The amount of ground water discharge is assumed to be equivalent to the daily flow equalled or exceeded 60 per cent of the time on these curves. These flows were calculated for four stations in the Rouge River basin and three in the Duffins Creek watershed (Table 7).

As is evident from Table 7, higher discharge rates are obtained in areas having larger proportions of sand and gravel on the surface. Because of the large area of surficial sands and gravels in the Duffins Creek basin, ground-water discharge is considerably higher in this basin than in the Rouge River watershed.

Average daily ground-water discharge in the Rouge and Little Rouge amounted to 0.087 and 0.094 mgd per square mile, respectively - an average of 0.091. Discharge from shallow ground water in Duffins Creek, as indicated by gauge 2HC006, is more than twice this value at 0.234 mgd per square mile. Similarily, ground-water discharge, as per cent of mean streamflow in Duffins Creek (50%), exceeds the average value for the Rouge and Little Rouge rivers (29%).

The estimated discharge of 0.104 mgd per square mile at station 2HC028 (drainage area of 30 square miles) on the Little Rouge Creek includes free flow of ground water from the Stouffville flowing well area. In 1974, this flow was estimated to be 1.4 mgd from a 9 square mile area of flowing wells, which corresponds to a discharge rate of 0.16 mgd per square mile.

GROUND-WATER RECHARGE

Estimates of ground-water recharge to all the major aquifers in the basin can be made on the basis of previously discussed 1) vertical component of ground-water movement and 2) ground-water discharge to streams. From these estimates, the amount of recharge to ground-water in the whole basin can be approximated.

The amounts of water moving vertically downward to the major aquifers (presented in Table 5) represent the approximate recharge to each aquifer. In the case of the Oak Ridges aquifer, the recharge is derived from direct infiltration of precipitation into the ground. For all the other aquifers, the recharge is derived from the percolation of water through confining materials above each aquifer.

On the basis of the downward movement estimates, the total recharge to all the major aquifers in the watershed was estimated to be 34.5 mgd. This is equivalent to an average infiltration rate of 0.22 mgd per square mile over the 152.1 square mile area over which there is downward

movement in the twelve major aquifers indicated in Table 5. Applying this average infiltration rate over the whole basin area of 268.5 square miles yields an estimated ground-water recharge value of 59.1 mgd. This is equivalent to an annual infiltration of 5.5 inches of precipitation over the basin.

The second method of estimating recharge to ground water involves using the average discharges of ground water to streams indicated in Table 7. Assuming that the loss of ground water through evaporation is negligible and that there is no significant annual net change in ground-water storage, the annual ground-water discharge to streams represents the amount of infiltration of precipitation to the water table. For the Rouge River basin, ground-water recharge can be obtained by multiplying the average discharge of 0.091 mgd per square mile by the total area of 129.7 square miles. This gives a recharge rate of 11.8 mgd. For the Duffins Creek and Petticoat Creek drainage areas, the discharge of 0.234 mgd per square mile is assumed representative and applicable to the 119.9 and 18.9 square mile areas, respectively. These values yield recharge rates of 28.1 mgd and 4.4 mgd, respectively.

The total recharge for the Duffins-Rouge basin adds up to 44.3 mgd. This is equivalent to an average recharge rate of 0.16 mgd per square mile, or 4.5 inches of precipitation over the total basin.

The estimates of recharge derived by the two methods vary significantly and this variation is attributed mainly to the assumptions and approximations made in each method. Errors in the vertically downward movement method could originate from any of the estimates of ΔH, L, A, and in the assumed infiltration rate of 0.2 mgd per square mile for the Oak Ridges aquifer. The combined effects of these approximations is not readily apparent, but the resulting recharge rate of 0.22 mgd per square mile seems reasonable. In the stream discharge method, probably the largest error can be attributed to fact that the method does not account for deep percolation of water. Consequently, the estimate of ground-water recharge will be smaller by an equivalent amount; therefore, the 0.16 mgd per square mile may be too low an estimate.

HYDROCHEMISTRY

GENERAL

Ground water is used extensively for municipal and rural domestic supplies in the watershed and for this reason ground-water chemistry is reviewed and compared to the permissible criteria for public supplies. The criteria cited for public supplies, i.e., municipal systems, are identical to private (single household) supplies and are based primarily on potable water quality standards.

Ground water is also used for irrigation of golf courses and commercial sod and consequently the classification of waters for irrigation is reviewed briefly. The classification is based primarily on the potentially harmful effects of reduced soil permeability caused by exchangeable sodium accumulation in soil, as measured by the sodium-adsorption-ratio (SAR) and the electrical conductivity of water.

Ground-water quality evaluations are based on a total of 44 samples taken in 1970 and 1974. Thirty-nine samples were taken from overburden domestic wells of varying depths, including one sample from a flowing well northwest of Stouffville. Three samples were taken from municipal wells and two samples were taken from wells that obtain water from or close to bedrock. The results of all the analyses are shown in Table 10 in Appendix E.

The intent was to determine natural water quality in as many of the commonly used aquifers as possible, including the major aquifers identified on maps 7 and 8. Consequently sampling was carried out on a group basis with wells in a group chosen as close together as possible and at as many different depths as possible. The close grouping of the wells was necessary in order to be able to compare the vertical variations of water quality in a small area. The locations, well numbers and the depths of each well are shown on Map 12.

BEDROCK WATER QUALITY

The two water samples obtained from bedrock wells 1430 and 4188 are of the sodium-bicarbonate type and the chemical diagrams for these wells reflect this, i.e., the sodium and bicarbonate axes are the longest. The high sodium concentrations are often associated with shale, and the sodium is probably derived from the salt that was deposited with sediments that make up the shale. Because of the high sodium associated with shale, base exchange of sodium for calcium in water has consequently increased the sodium and reduced the calcium content in water. This results in low water hardness.

Map 13 indicates the locations of bedrock wells in which "salty" and/or "sulphurous" waters were encountered, or in which natural gas was found during well construction. In the southern part of the Regional Municipality of Durham, some overburden wells end close to the top of rock and therefore also report problems with water quality. In view of this, ground-water exploration in the southeastern parts of the basin should be restricted to overburden deposits that are not in direct connection with bedrock. The overburden thickness shown on Map 4 can be used as a guide for drilling wells in the overburden. Wherever possible, overburden wells should end 10 to 20 feet above bedrock to reduce the likelihood of encountering poor-quality water.

OVERBURDEN WATER QUALITY

Private Wells

Most waters in overburden formations are of the calcium-bicarbonate type, i.e., calcium concentration is higher than any of the other cations and bicarbonate is higher than any of the anions (Figure 7). This consequently results in the characteristic shapes of the chemical diagrams shown on Map 12, where the uppermost lateral axis is the longest and the other two axes are progressively smaller in length. Two figures do not conform to this shape: those for well 1480 and well 3271. In both wells, the calcium and chloride concentrations predominate. The reason for the high chloride concentrations has not been investigated but they probably indicate contamination rather than natural water quality.

In comparing the shapes of the chemical diagrams, it is obvious that ground-water quality in the overburden does not vary significantly with depth, or from one part of the basin to another. The electrical conductivity at most locations decreases slightly with depth, indicating that the water contains less dissolved solids in deeper wells. However the difference is small.

Water samples from the three groups of wells in the Oak Ridges aquifer indicate a generally smaller concentration of dissolved solids than in the southern aquifers. Consistent differences in other parameters are not obvious.

Flowing well 8065A is typical of wells in the Lemonville area on the Oak Ridges Moraine and indicates the chemical composition of water throughout the flowing well area. Its chemical composition is similar to the other samples obtained from the Oak Ridges aquifer.

Municipal Wells

Water from three municipal wells was sampled for inorganic chemical analyses: Stouffville well #5 (8212), Markham well #2 (3899), and Unionville well #2 (10992). These samples indicate that ground water of generally good quality is available for domestic use from three of the large aquifers that have been identified in the basin.

Stouffville well #5 obtains water from the Oak Ridges aquifer sand and gravel at a depth of approximately 23 feet. The water is of the calcium-bicarbonate type and with a TDS of 340 ppm, is typical of ground water in the Oak Ridges aquifer complex. The iron content of 0.95 mg/l is high, as is the total hardness of 268 mg/l calcium carbonate. Iron removal is part of the municipal system to reduce the high levels to acceptable average concentrations of 0.30 or lower.

Markham well #2 is a flowing well that obtains its water from sand and gravel at a depth of 140 feet in the upper Markham aquifer unit. The water is also of the calcium-bicarbonate type, with a total dissolved solids value of 212 mg/l. The hardness value of 156 mg/l falls in the "hard" class but is well below the average values usually occurring in ground water in overburden. The water sample from this well indicates the generally good quality of water than can be expected from the upper Markham aquifer unit in the area.

Unionville well #2 is constructed in sand and gravel in the lower Unionville aquifer unit at a depth of 125 feet. The well flowed at the

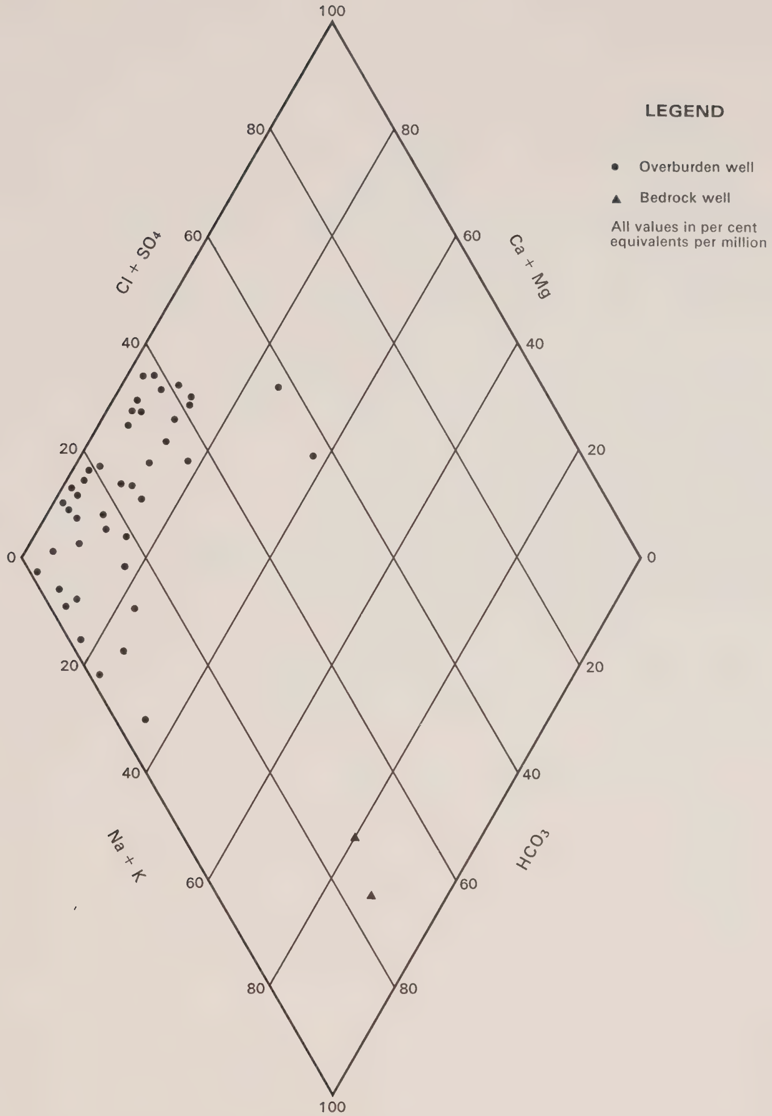


Figure 7. Major-ion chemistry of ground water.

time of construction in 1972. The water is very hard (200 mg/l) and contains iron in excess of the 0.3 mg/l permissible criteria for public supplies. However with proper treatment, the high iron does not restrict use of the water for either private or municipal purposes. The water contains a low total dissolved solids concentration of 270 mg/l and the low TDS concentration appears to be characteristic of most of the deeper overburden aquifer units in the Duffins-Rouge basin.

SUITABILITY OF WATER FOR DOMESTIC USE

Raw ground water to be used for domestic use should meet certain quality criteria in order to minimize or avoid water treatment that can add considerable cost to a private water-supply system. Water quality much above such criteria can make the supply uneconomical if extensive treatment is required, and in some instances treatment of private domestic supplies is not possible at all.

Most unpolluted ground waters are free of organic chemicals, radioactive and microbiological parameters, and of objectionable physical parameters. Therefore only the inorganic chemical parameters are used in this study to assess the suitability of ground water for domestic uses. The quality parameters are compared to the permissible criteria quoted by the Ministry of the Environment (1974), which represent concentrations that should not be exceeded in order to minimize the necessity for treatment of supplies. Because there are generally insignificant variations (with time) in unpolluted ground-water quality, the results of the single samples taken in 1970 and 1974 are considered representative of average water quality in the wells.

The most common inorganic chemical parameters of concern in ground water and their permissible criteria are:

Chloride	- 250 mg/l
Iron	- 0.3 mg/l
Nitrate (as N)	- 10 mg/l
Sulphate	- 250 mg/l
Total Dissolved Solids	- 500 mg/l

In addition, the classification of hardness of waters is as follows:

less than 60 mg/l ($CaCO_3$)	- soft
61-120	- moderately hard
121-180	- hard
more than 180	- very hard

There are generally no acceptable criteria for hardness of water, as this depends on individual requirements and preferences. However, some degree of softening may be desirable for very hard waters.

The distribution of values for all the six parameters is presented in figures 8 to 13, and each parameter is discussed briefly in subsequent sections.

In summary, natural inorganic ground-water quality is generally acceptable for private and public water supplies. The most bothersome elements are the high concentrations of iron and water hardness, both of which can be lowered to acceptable levels by readily available treatment

systems. Chlorination of all supplies, in conjunction with appropriate treatment for iron and hardness, is desirable to ensure maximum protection against nuisance and pathogenic organisms.

Chloride

Restrictions on chloride content in domestic water supplies is generally based on palatability requirements rather than on physiological effects. The concentrations of chlorides at which water tastes salty vary from person to person, but the criterion accepted by the MOE is 250 mg/l. There is only one well in the basin that exceeds this criterion - well 3271 (Figure 8). This is a drilled well 74 feet deep in the upper Unionville aquifer. The reason for the high chloride content is not obvious, except that the well is located adjacent to Hwy. 7 and may be contaminated by the seepage of salty highway meltwater directly into the well.

The mean chloride content for 42 samples from overburden wells is 37 mg/l (Table 8), while for the two samples from domestic wells in bedrock the mean is 94 mg/l.

There are no economical home treatment systems to eliminate salty taste due to chlorides. An alternate source of supply is the most expedient solution.

Iron

Iron is not considered toxic at concentrations usually found in ground waters, but it is objectionable in domestic supplies because of the reddish colour and the bitter taste it can impart to drinking water and because it can stain porcelain plumbing fixtures and laundry.

Nearly one-half of the domestic wells sampled contained iron concentrations in excess of the permissible criteria of 0.3 mg/l (Figure 9). An average for the 42 samples from overburden wells is 0.61 mg/l, and for the two samples from bedrock, the average is 1.2 mg/l. Nine of the total 44 samples contained iron in excess of 1.0 mg/l, a considerable excess over the permissible criteria. At this concentration, water treatment for iron removal is highly desirable.

High iron concentrations in water can be found in virtually any aquifer, either shallow or deep. It is expected that because of the potentially high iron content in shales, ground waters in shale can contain higher amounts of iron than waters in overburden. Iron removal systems for single household use are readily available and can be used to eliminate problems caused by high iron contents in domestic waters.

Nitrate

Nitrate concentration in water in excess of 10 mg/l nitrogen is generally regarded dangerous for use in infant feeding formulae. Infant methemoglobinemia, a disease characterized by certain specific blood changes and cyanosis (McKee and Wolf, 1963, p.224), can be fatal to very young infants if proper medical treatment is not received. No mention is made in the literature of specific criteria for adult consumption, except to infer that nitrates at levels that usually exist in uncontaminated ground water are considered non-toxic to adults (MOE, 1974).

Samples from five wells contained nitrates in excess of the permis-

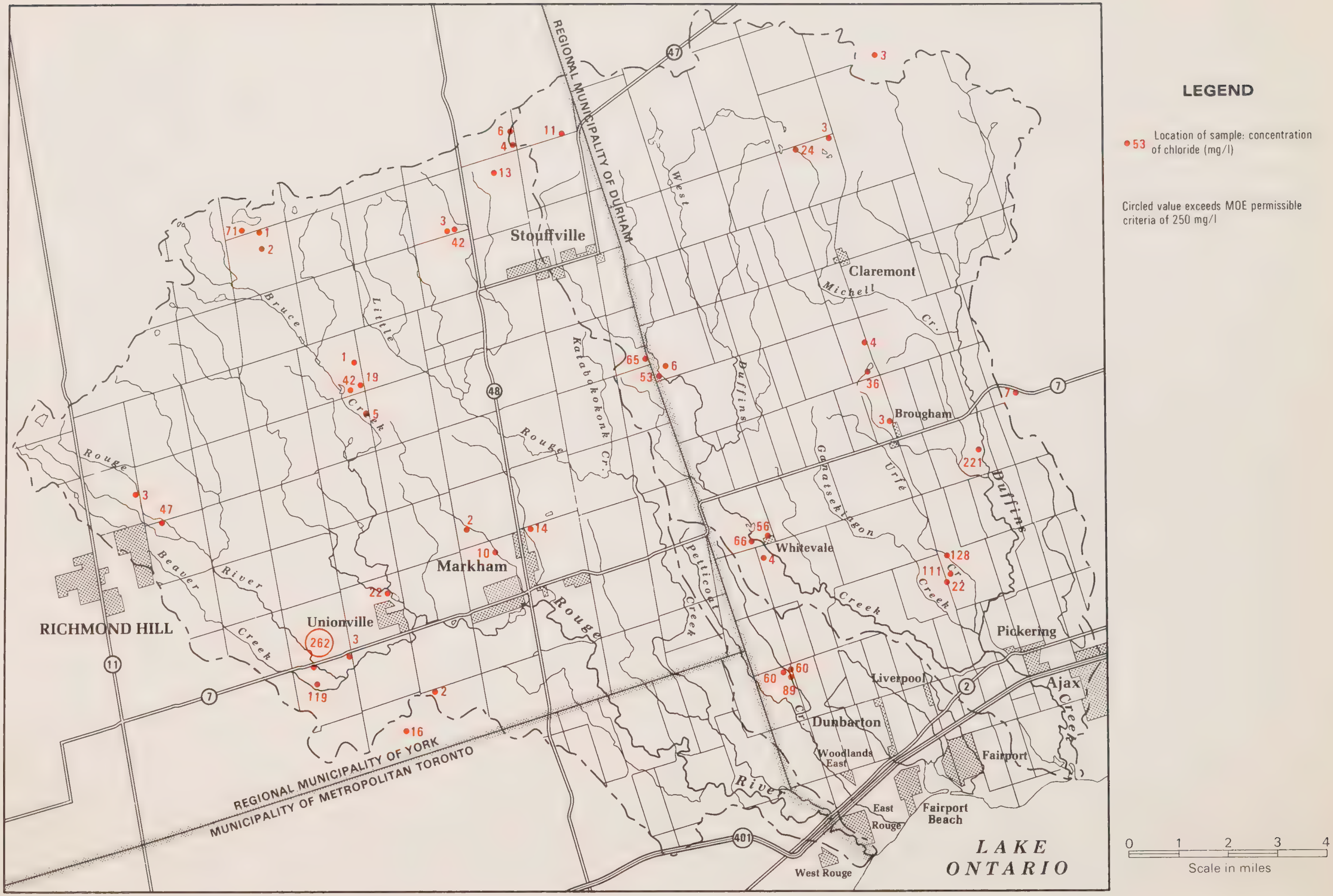


Figure 8. The concentration of chloride in ground water.

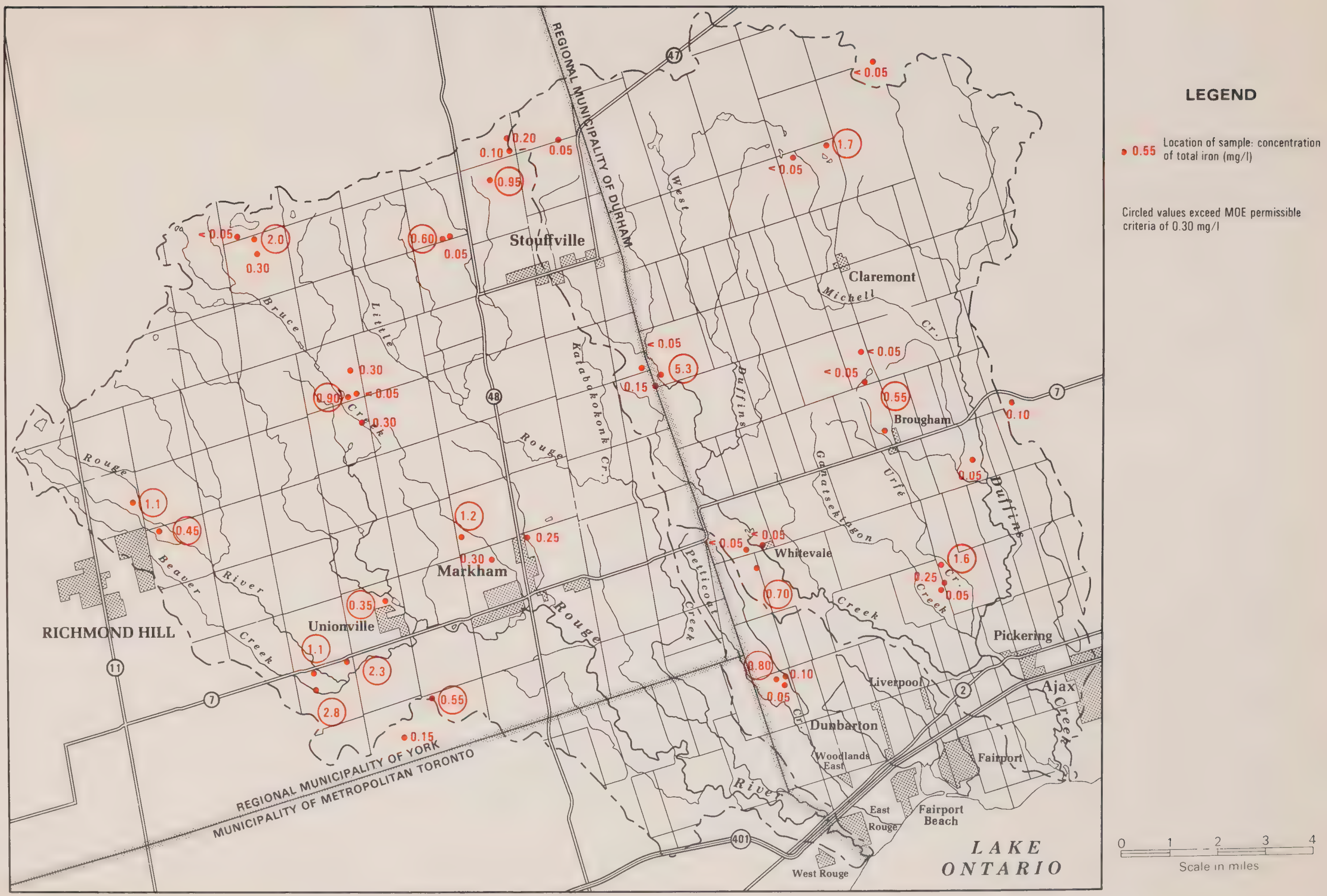


Figure 9. The concentration of total iron in ground water.

Table 8. Ground-Water Quality Summary

			Ionic Concentrations (mg/1)									Total Alkalinity as $CaCO_3$ (mg/1)	Total Hardness as $CaCO_3$ (mg/1)	Total Dissolved Solids (mg/1)	Specific Conductance (at lab) (mmhos/cm)
A. Overburden Samples (42 samples)		pH (at lab)	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3 as N	Total Iron				
	Max.	7.8	222	39	111	16	595	155	262	33	5.3	488	716	1000	1329
	Min.	7.0	30	2	2	0	205	1	1	.16	<0.05	168	136	207	355
	Mean	7.5	103	17	19	2.1	323	37	37	2.7	0.61	261	311	440	608
A. Bedrock Samples (2 samples)	Mean	8.0	18	7	190	5.7	498	5	94	<0.2	1.2	202	73	630	1020

sible criteria: well 1334 - 12 mg/l; well 1541 - 13 mg/l; well 1563 - 11 mg/l; well 2884 - 20 mg/l, and well 3612 - 33 mg/l (Figure 10). These levels of nitrate probably indicate a degree of pollution of the water supplies. The source of contamination in well 3612 may be due to animal waste associated with a dog kennel operation on the property. The possible sources of contamination on the other four properties are not readily apparent.

There are no home treatment systems available to reduce nitrate concentrations in water and consequently, the abatement of nitrate pollution depends on preventative measures taken in the construction of domestic wells.

To minimize the chances of contamination, wells should be located as far as practicable from any obvious sources of contamination such as domestic septic systems, feedlots and barnyards, and regularly (heavily) fertilized farm fields. In cases of shallow bored wells or wells constructed by digging equipment, it is especially important to seal the well casing at the surface of the ground with impermeable materials. This would help to prevent the entry of surface water or other foreign materials into the well or the shallow water-bearing formation. Proper well construction is usually the best assurance of a contamination-free well.

Sulphate

Criteria on sulphate concentrations in domestic well supplies are based primarily on its laxative effects on unacclimatized users, rather than on taste or toxicity. The maximum sulphate concentration permissible for domestic supplies in Ontario is 250 mg/l.

All samples in the basin contain less than 250 mg/l sulphate (Figure 11), with a mean value of 37 mg/l for overburden wells and a mean concentration of only 5 mg/l for the two bedrock wells. Sulphate concentrations at these levels will present no problems in domestic water supplies.

Under some circumstances, sulphate in an anaerobic environment (which usually exists in ground water) can be converted to hydrogen sulphide gas by sulphate-reducing bacteria. The "rotten egg" odour of this gas is characteristic and waters having this smell are often called "sulphurous". The distribution of the nine wells in which "sulphurous" waters have been reported by drillers is shown on Map 13. Three of the wells obtain water from overburden sources and six from bedrock. All the bedrock wells are in the vicinity of Ajax and Pickering.

Home treatment systems consisting of chlorination-filtration and/or carbon filtration are readily available to remove the pungent odour and taste problems due to hydrogen sulphide gas. However, there appear to be no commercial home treatment systems specifically for sulphate reduction.

Total Dissolved Solids

Total dissolved solids (TDS) content of water represents the sum of dissolved cations and anions in water, the main ones being sodium, potassium, calcium, magnesium, bicarbonate, chloride, sulphate and nitrate. High TDS in itself does not restrict the use of water for domestic purposes. Rather, it is the high individual ion concentrations that contribute to the TDS value that restrict the use of the water.

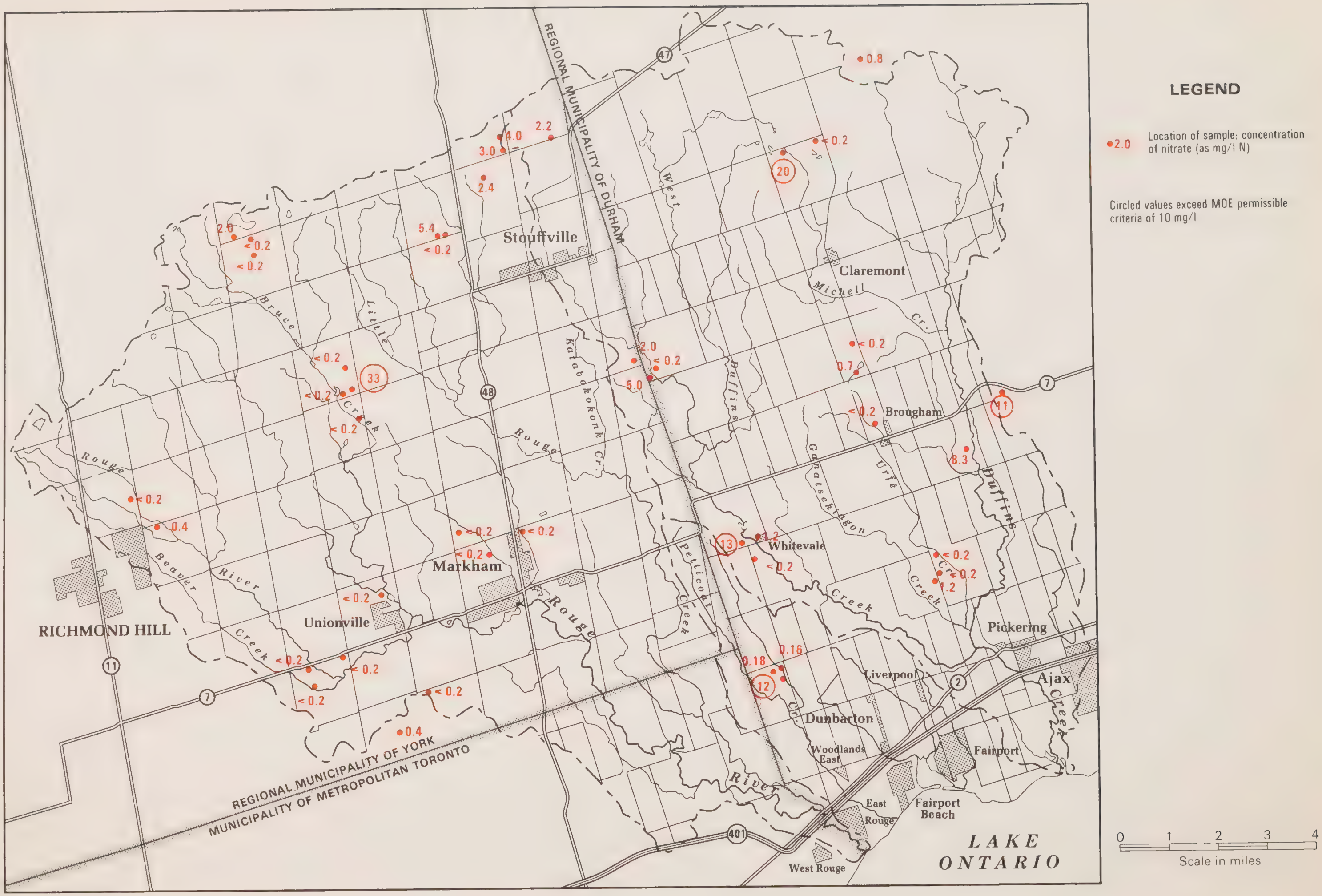


Figure 10. The concentration of nitrate in ground water.

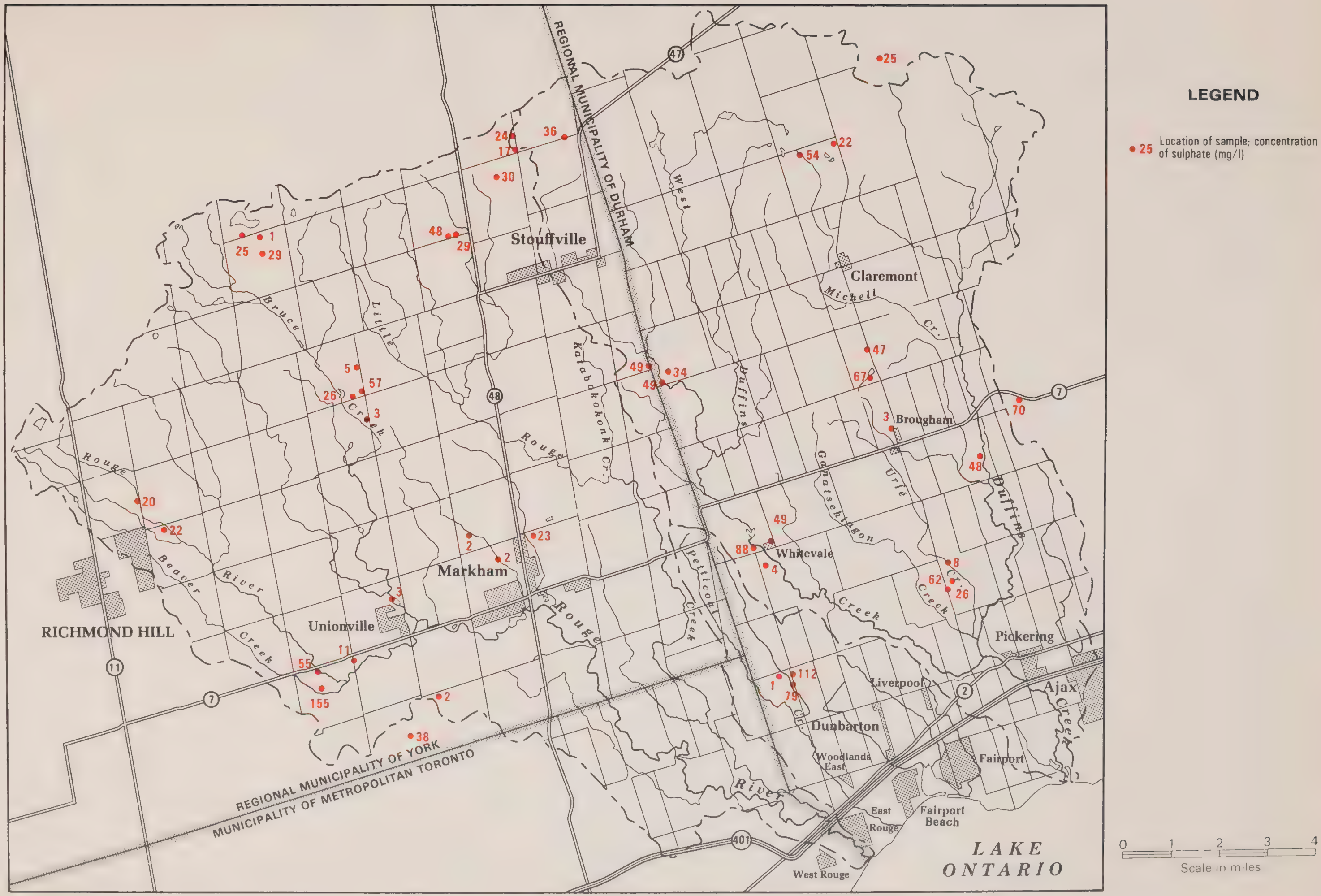


Figure 11. The concentration of sulphate in ground water.

The MOE permissible criterion for TDS is 500 mg/l. This criterion is somewhat arbitrary and waters with much higher concentrations can be consumed with no ill effects.

Fourteen of the 42 overburden wells sampled in the basin contain waters having more than 500 mg/l TDS (Figure 12). In most of these cases, the waters contain high calcium or sodium and bicarboante concentrations, none of which by themselves limit the use of the water for domestic supplies. The average for the two bedrock wells (630 mg/l) is much higher than for the 42 overburden wells (440 mg/l).

None of the TDS values in the watershed should be of concern to domestic users, including the maximum value of 1000 mg/l (in well 1480), which is due primarily to the high chloride content in the water. There are no domestic treatment systems available to reduce the TDS per se. Reduction, when it does occur, is usually the result of water treatment for high concentrations of one of the major cations or anions.

Hardness

Hardness of water is due primarily to the concentrations of calcium and magnesium ions in water. The effects of hard water on the consumption and cleaning power of soap are well-known.

Except for the two water samples from bedrock and one sample from the Markham municipal well, all samples are classified "very hard". The mean for the 42 samples from overburden wells is 311 mg/l, and 73 mg/l for the the two bedrock wells. A large proportion of the overburden samples contained hardness in excess of 400 mg/l, with the maximum concentration of 716 mg/l found in well 11219 (Figure 13). In all cases calcium is the main ion contributing to the high hardness values.

Hardness can be readily reduced by home softening systems available commercially. The need for softening is dependent primarily on economic and convenience considerations rather than on health hazards.

SUITABILITY OF WATER FOR IRRIGATION

Ground water is used for the irrigation of golf courses and commercial sod in many areas of the basin (Map 14). Using waters of unsuitable quality may, over a period of time, reduce the permeability of soils in the irrigated areas and thereby reduce the infiltration of irrigation water into the soil.

The suitability of ground waters for irrigation is based on the two parameters of sodium-adsorption-ratio (SAR) and electrical conductivity. The method of classification was developed by the United States Salinity Laboratory Staff (1954) in which the SAR is calculated by the following equation:

$$SAR = \frac{Na+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

where Na^{+}, Ca^{++} and Mg^{++} represent the concentrations (in milliequivalents per litre) of the respective ions.

Proportionately high sodium concentrations, compared to the sum of calcium and magnesium, will result in high SAR values.

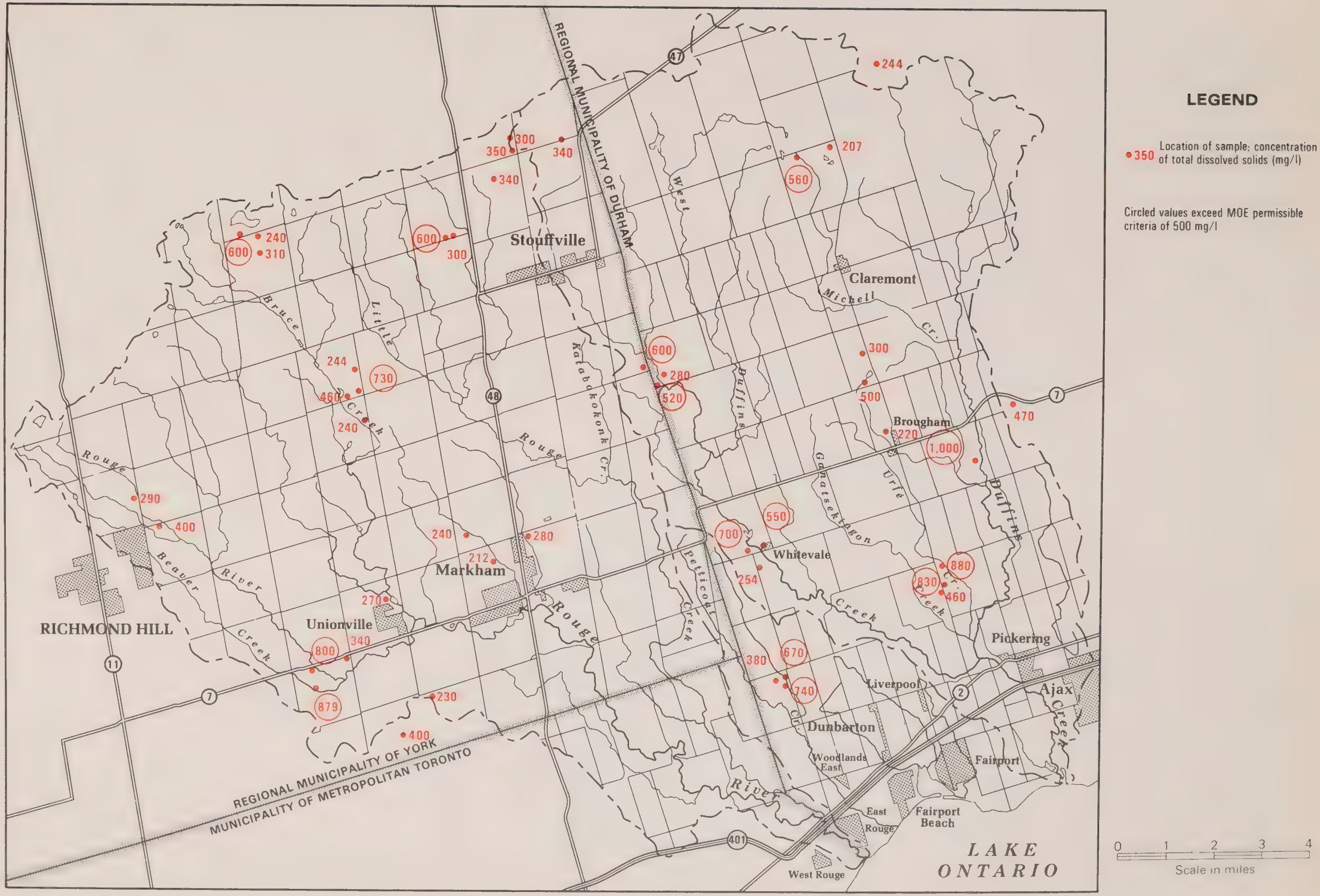


Figure 12. The concentration of total dissolved solids in ground water.

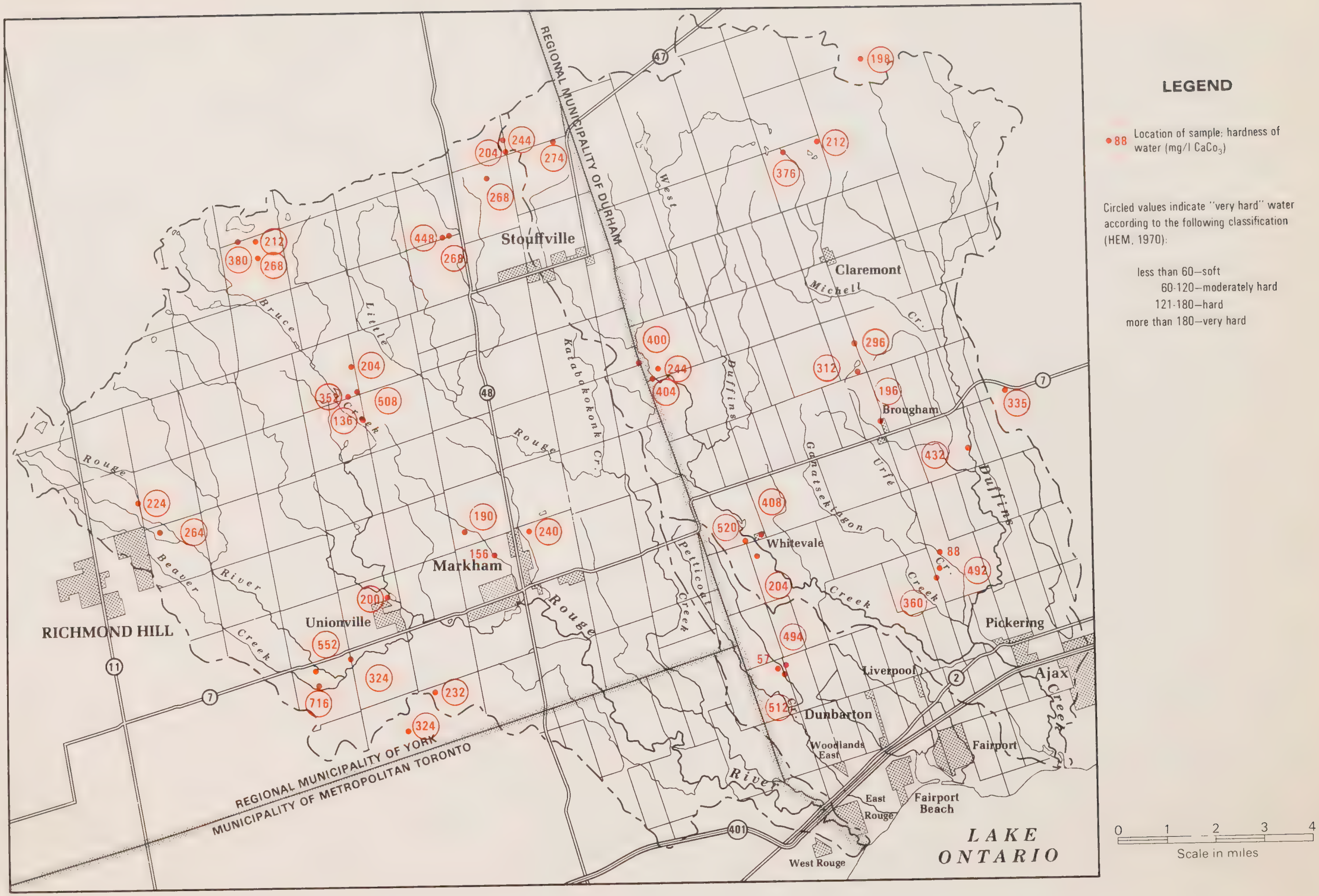


Figure 13. Total hardness of ground water.

The SAR represents the sodium (alkali) hazard and is plotted on the vertical axis of the diagram shown in Figure 14. The electrical conductivity of the water is plotted on the horizontal axis and represents the salinity hazard. The sodium and salinity hazards are used conjunctively to classify irrigation waters according to the descriptions provided on Figure 14.

The majority of water samples in the basin fall in the C2-S1 class, which is a medium-salinity, low-sodium hazard class in which the waters can be used for irrigation on almost any soil, including low-permeability tills and clays. Eleven samples are in the C3-S1 class in which the salinity hazard is high and the water should not be used for irrigation on soils with restricted drainage.

Ground water in well 1430 is obtained from shale bedrock and has a high sodium and salinity hazard, which makes the water unsuitable for irrigation except under special soil management conditions. Probably similar restrictions apply to the use of ground water obtained from shale bedrock throughout the basin.

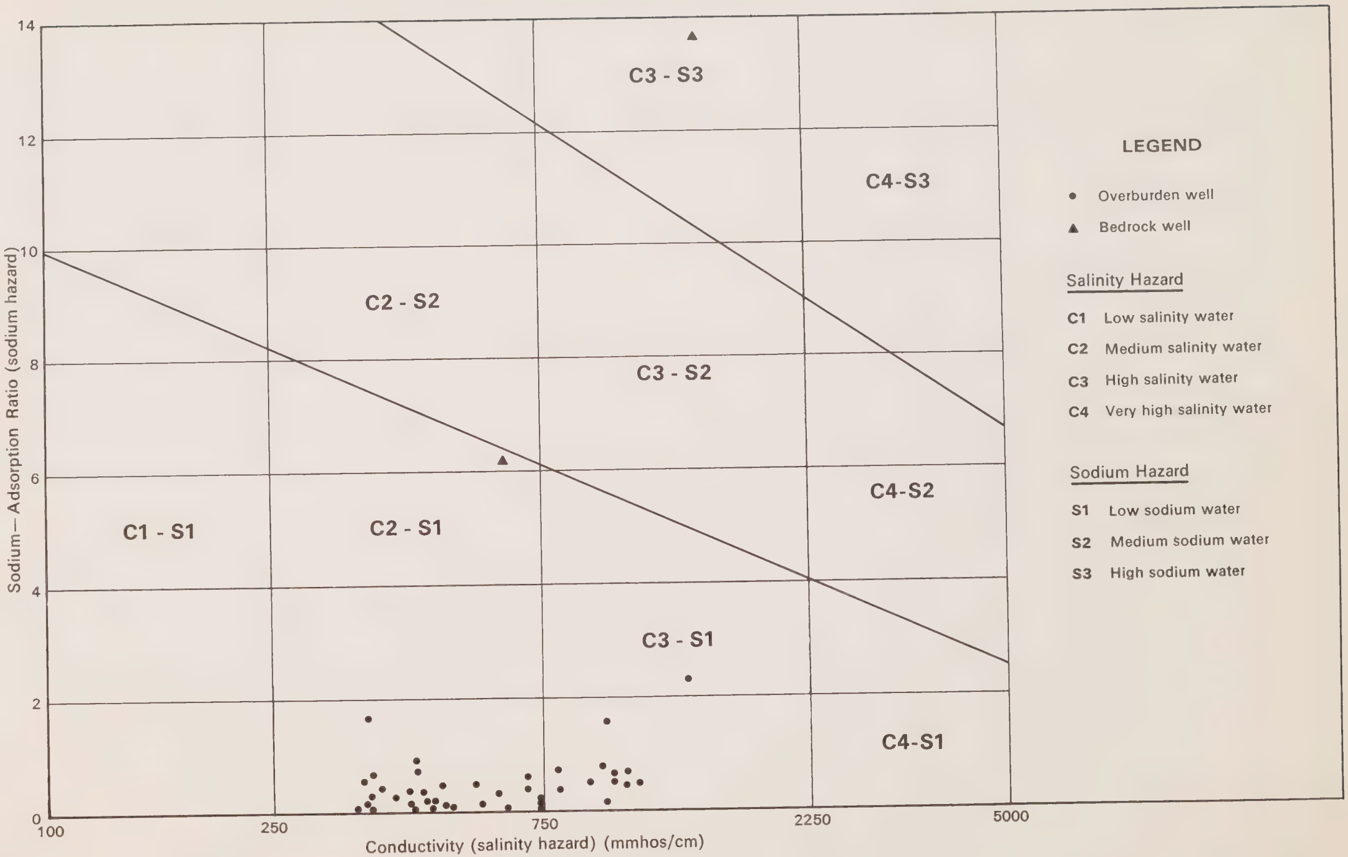


Figure 14. Suitability of ground water for irrigation (classification after U.S. Salinity Laboratory Staff [1954]).

GROUND-WATER USE AND DEVELOPMENT

GENERAL

Ground water is an important source of supplies for many of the major water requirements in the basin and in many areas it is the only economic alternative for high demands of potable water. All major municipal water-supply systems in the basin draw water from local aquifers that to date have adequately met demands. Similarly, high demands required by industrial and agricultural activities in the watershed have been satisfied. However, local interference with existing supplies has also been recorded in the basin and locally, poor ground-water availability has restricted development of activities requiring large amounts of good quality water.

Major ground-water development is associated with municipal takings in the Markham-Unionville area in the Rouge River basin. In 1975, municipal withdrawals in this area were close to 80 per cent of all the municipal takings in the watershed and made up approximately 23 per cent of the 14.7 mgd total authorized by water-taking permits (table on Map 14). Because of these high water demands, it has been necessary to consider a large-scale provincial water and sewage scheme to service the Markham-Unionville area for the future. The scheme, known as the York-Durham Project, is based on water supply from Lake Ontario which will ensure adequate supplies for projected long-term growth immediately north of Metropolitan Toronto.

In addition to the large municipal withdrawals, ground water meets industrial requirements of the sand and gravel industry, provides water for golf course irrigation, and is an essential base for a wide range of agricultural-related activities. To a lesser extent, ground water is used locally in the Lemonville area to supply water for recreational ponds.

Subsequent discussions of ground water in the basin relate directly to the water uses shown on Map 14, which is based on several sources of data on file with the Ministry of the Environment. The most important source is the Permit to Take Water program, which is administered by the Ministry. This program relates directly to Section 37 of the OWR Act, which states that all surface- and ground-water takings in excess of 10,000 gpd, except those for fire fighting and domestic and farm requirements, require a permit issued by the Ministry. The major types of takings and their authorized rates are indicated in the table on Map 14 under the heading "Authorized by Permit". Section 37 also provides for the resolution of water-supply interference. The Ministry's interference files are the basis for indicating past interference cases on Map 14. Not shown on the map are domestic (private) takings, which occur throughout the basin. The locations of these takings are in essence shown on Map 6 where most wells relate to private withdrawals.

The authorized water takings and past interference cases shown on Map 14 reflect the general land-use development trends in the basin. Most permitted takings are found in the Rouge River basin with only a few located in the Duffins Creek watershed. Within the Rouge River system, major development has occurred in the area of Markham and Unionville and in the vicinity of Stouffville to the north. Concentrated urbanization occurs also near Richmond Hill in the extreme western part of the basin, but much of this development does not rely directly on ground water in the watershed.

MUNICIPAL SUPPLIES

Municipal supply is the most significant ground-water use in the area. An estimated total of 4.3 mgd was pumped by municipalities in 1975, which represents approximately two-thirds of all the permitted withdrawals in the watershed during the year. The largest takings are centred around three municipal systems located within the basin at Markham, Unionville, and Stouffville, and around two systems operating just outside the basin boundary at Thornhill and Oak Ridges. All systems withdraw water from aquifers within or extending into the basin.

Markham is serviced by a system of two production wells, one in the lower and the other in the upper Markham aquifers. Well #1 was completed in 1960 and well #2 in 1964; both wells flowed at the time of construction. The two wells have the highest rated capacity of any of the 13 municipal production wells shown on Map 14, with each of the two wells being capable of producing more than 1 mgd. In 1975, their combined daily rate of withdrawal was 1.51 million gallons, or 52 percent of the amount authorized by permit.

The Unionville system contains three wells. Wells #1 and #2 were constructed in 1964 and 1972 in the lower Unionville aquifer and well #3 was completed in 1967 in the upper aquifer. All three wells flowed at the time of construction. The total system capacity is relatively small in comparison to other systems, producing only an average of 0.45 mgd in 1975. This represents 54 per cent of the authorized daily amount for the three wells.

The Stouffville system contains two wells, both of which are constructed in shallow formations in the Oak Ridges aquifer. Well #5, completed in 1960, is only 50 feet deep and obtains water from the interval from 24 to 50 feet; well #8 was completed in 1966 and receives water at a depth of 45 to 70 feet. The 1975 production from these wells amounted to an average daily taking of 0.73 million gallons, or approximately 53 percent of the system's authorized amount.

There are six high-capacity municipal wells outside the basin, each constructed in an aquifer that extends into the basin and therefore capable of influencing water levels in wells inside the watershed. Two wells belong to the Oak Ridges community system northwest of the basin boundary and four belong to the Thornhill water-works system just outside the basin boundary southwest of Unionville.

The Oak Ridges wells are deep wells within the Oak Ridges aquifer system; well #1, completed in 1961, is 379 feet deep and well #2, constructed in 1969, is 390 feet deep. The combined capacity of the two wells is 1.01 mgd and in 1975 production from these wells amounted to 0.13 mgd, or 13 percent of the authorized amount. It is unlikely that at these low rates of withdrawal there would be any noticeable effects on water levels in nearby wells within the basin.

Because of their proximity to the basin, four of the seven wells in the Thornhill system could affect water levels in wells in the Unionville aquifers southwest of Unionville. Don Mills wells #1, #2 and #3 are constructed in the lower Unionville aquifer system at depths varying from 98 to 120 feet, while the Steeles-Pharmacy well is at a depth of 360 feet. Don Mills wells #1 and #2 were both completed in 1957 and well #3 was put into production in 1967. The Steeles-Pharmacy well was completed in 1972.

The combined production from the four wells in 1975 averaged 1.49 mgd, which represents 56 percent of the rate authorized by permit. A marked water-level decline in observation well 106 in 1969 and 1970 (Figure 15) is attributed to increased pumping by Don Mills wells #1, #2, and #3. A general water-level recovery in the period from 1971 to 1975 correlates with decreased annual pumping in the wells during this period. The effects of these production wells on water levels in nearby wells in the basin is not documented. Presumably, the effects to date have not been noticeable.

INDUSTRIAL, COMMERCIAL AND AGRICULTURAL SUPPLIES

Withdrawals at sand and gravel operation sites are the primary industrial uses of ground water in the basin and most of these are located on the Oak Ridges moraine north of Stouffville. The water is used in washing processes which are usually closed systems in which the water is recycled through settling ponds, but make-up water is required continually to balance water losses through evaporation and seepage. This make-up water can be considerable in some instances, as 1.06 mgd was used by seven permitted operations in 1975. Next to municipal withdrawals, industrial takings were the largest of the permitted takings in 1975.

The irrigation of golf courses in the basin is an increasing practice that can periodically demand appreciable amounts of good quality water. A number of golf courses in the Rouge River basin north of Toronto cater to urban population demands, and because of variable precipitation in the area during the summer, irrigation of fairways and greens is a necessary practice. This generally necessitates high-capacity ground-water withdrawals for short periods of time. In 1975, these withdrawals totalled 0.47 mgd for the seven golf courses under permit.

The irrigation of market crops appears to be the primary agricultural use of ground water in the basin, while the irrigation of turf sod and nursery stock occurs less frequently. The demand for livestock watering has not been investigated. In most irrigation cases, ground water is used to recharge storage ponds from which the water is withdrawn. In 1975, this consumption amounted to 0.31 mgd by the six permitted takings. Five of the six takings occurred in the vicinity of Markham and Unionville.

PRIVATE SUPPLIES

Private supplies consist mainly of individual wells constructed for domestic household needs. These takings to not require a permit and are therefore not located on Map 14. However, an indication of the location and density of these takings can be obtained from Map 6, where almost all wells refer to private domestic wells. Private supplies other than for domestic purposes consist of flowing wells supplying recreational ponds north of Stouffville.

Domestic wells service primarily rural areas of the basin and as such, their distribution is governed by the density of farms and by individual houses in and adjacent to small unserviced hamlets and villages. Most concentrated domestic takings are associated with settlement outside of Metropolitan Toronto boundaries to the north and

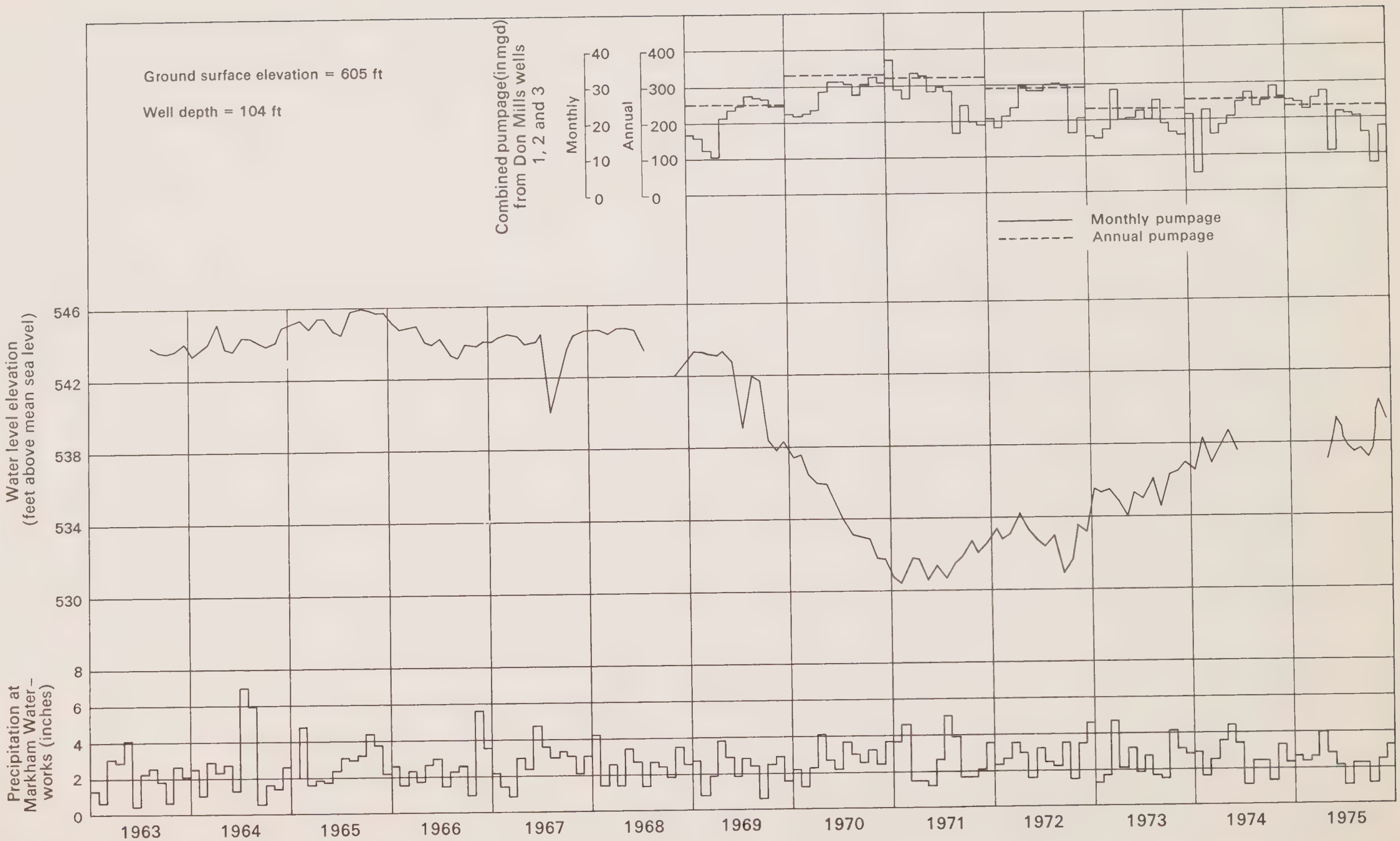


Figure 15. **Water-level hydrograph of observation well 106 correlated with monthly and annual pumpage from Don Mills municipal wells.**

east. Two especially dense areas are located north of Highway 401 east of Pickering, and around Markham and Unionville. In both of these areas, all existing wells could not be plotted on Map 6 because of their high density.

There are approximately a total of 3800 private domestic water wells in the basin, which in 1975 supplied an estimated rural population of 21,500 (TEIGA, 1976). At an assumed per capita water consumption of 100 gpd, the total use of ground water through private wells amounted to 2.2 mgd. This is a small value in comparison to the amount used by permitted takings, and individual domestic requirements usually represent insignificant point withdrawals in relation to the total available resource.

Domestic water requirements for individual households are usually small, in the order of 2 to 5 gpm for short periods during the day, and as such, ground water is readily available in most areas in the basin either through small-diameter drilled wells or large-diameter bored wells.

WATER USE CONFLICTS

Reported interference cases in the basin have been relatively minor and except for past complaints attributed to municipal pumping at Markham and Unionville, the past cases have been of limited scope and duration. Four general categories have been inventoried and are indicated on Map 14. These are, in order of frequency of occurrence: 1) dewatering-7 cases, 2) municipal water-supply takings-5 cases, 3) private supplies-3 cases, and 4) irrigation-2 cases.

Most frequent complaints have related to dewatering projects associated with road construction and gravel pit dewaterings. These have occurred primarily in the vicinity of the more heavily developed areas north of Richmond Hill, near Markham, and in the Town of Pickering. Interferences related to municipal takings have occurred exclusively in the Markham-Unionville area, while interference related to irrigation and private takings have occurred mainly in the Markham-Unionville and Stouffville areas.

Interference with domestic supplies in usually shallow wells adjacent to or near large takings have been most common and the successful restoration of supplies has been brought about through the Permit to Take Water program administered by the Ministry of Environment. The permits in each case were issued with standard special conditions requiring the permit holder to rectify interference with previously existing uses.

In the three cases involving domestic takings (which do not require a permit), the two cases near Lemonville involved flowing wells and the complaint south of Unionville arose as the result of construction of new domestic wells nearby. With the Ministry as an intermediary, all cases were resolved by the involved parties.

With the future development of the York-Durham water and sewage system over a 10- to 15-year period (from 1975 to 1985+), the present Markham-Unionville municipal wells will be phased out and no new interference claims are anticipated in the area. However, interference claims may develop during the construction phases of the York-Durham scheme as construction dewatering is anticipated throughout the project. Two areas in particular may be sensitive to interference. One is in the

sand plain area south of Unionville where a number of domestic wells presently obtain water from shallow sand lenses and the other area is in the Town of Pickering in the southern part of Duffins Creek basin. The latter area contains numerous shallow bored wells that obtain marginal quantities of water from shallow overburden. Dewatering of any of the sand lenses could result in interference with existing supplies. It is anticipated that water levels in deep wells will not be affected significantly by the York-Durham dewatering schemes.

USE TRENDS AND POTENTIAL FOR FUTURE DEVELOPMENT

As late as the 1950's, ground-water development in the basin was restricted primarily to low-demand domestic takings associated primarily with agricultural activities. However in the past 15 years (since about 1960), the peripheral areas around Toronto have developed at a rapid pace and more and more of the original rural land has been used to support urban-based industrial, commercial and housing developments requiring large quantities of water. Together with this development, the demand for ground water has increased at a rapid rate, especially in the area of Markham and Unionville and in the vicinity of Stouffville. This increase is evidenced by the large number of wells drilled in these areas since 1960, supported by the fact that the construction of all high-capacity municipal wells at Markham and Unionville has occurred since 1960. Rapid development has also taken place east of Toronto in the Ajax-Pickering area, where again ground water has been the primary source of supplies.

It has now come to the point where significant future land development may soon be restricted by the availability of ground water. This realization has led the Province of Ontario to devise a major sewage and water-supply scheme to service the densely populated areas directly north of Toronto and an area of planned urban growth (North Pickering Project) to the northeast in the Town of Pickering.

The provincial sewage and water scheme will extend Toronto's Lake Ontario water-supply system northward into the basin to service the Markham, Unionville and peripheral areas in stages from 1975 to 1985. In addition, this scheme will provide water to the Ajax-Pickering area in the east and to the provincial urban development scheme in the Town of Pickering. As the integrated servicing scheme progresses, the reliance on ground water for municipal supplies will be reduced and existing ground-water sources at Markham and Unionville will probably be gradually phased out.

The North Pickering Project involves the staged development of a planned community in the Duffins and West Duffins Creek areas in the Town of Pickering. Pending the completion of the regional water-supply pipeline associated with the York-Durham scheme, interim ground-water supplies for the population in stages 1 (1977 to 1985, population 30,000) and 2 (1985 to 1990, population of 85,000) of the project are currently under consideration. However, there are only limited high-capacity water-bearing formations in the area and it is expected that ground water cannot be used to supply the ultimate large demands required by the total project.

It is anticipated that ground water will continue to play an essential role in land use development in the basin outside the area to be serviced by the York-Durham scheme. In the Duffins Creek basin where

ground-water availability is generally not adequate in many areas to meet large requirements, future development will have to depend largely on alternate sources of supply. However, in the Rouge River watershed, ground water can continue to provide essential supplies from the Markham, Unionville and Victoria aquifer systems for a large proportion of the population. Good ground-water potential in the Oak Ridges aquifer will continue to meet the needs of Stouffville and other areas to the north on the Oak Ridges Moraine as the population density continues to increase peripheral to Toronto. At least in the initial stages of development, this will lead to an increased use and dependence on ground water in the northern areas of the basin.

Two aquifer systems outside the York-Durham scheme will offer a good potential for large quantities of water - the Oak Ridges and the Markham aquifer systems. The Oak Ridges aquifer system holds by far the best potential for future development, representing approximately 50% of the ground water in all the defined aquifers in the basin (Table 5).

Present development of the aquifers in the Oak Ridges complex is primarily through domestic wells that produce individually an estimated 3-10 gpm. With approximately 300 domestic wells in the area, and each producing at an average rate of 5 gpm, the estimated domestic consumption would be 1500 gpm, or approximately two million gallons per day. Adding this to the Stouffville municipal well capacity of 1.4 mgd, the total development to date would be close to 4 mgd. This is about 23 per cent of the estimated 17.2 mgd annual recharge to the complex. On the basis of these approximate estimates, the future potential for development is good. However, the net potential of 13.2 mgd applies for the total 86 square mile area of the complex and individual well yields in a particular area will be dictated by local hydrogeologic conditions. Although extensive test drilling would be required in specific areas on the Oak Ridges Moraine considered for development, high-capacity wells or well systems capable of 1 mgd or more should be possible. However, present ground-water development in the flowing well area northwest of Stouffville is close to maximum, and new development in the area may lead to the stoppage of flows in existing wells and to the long-term dewatering of the aquifer system in the area.

The second aquifer system that has a good potential for future development is the Markham system (upper and lower units collectively). The most attractive parts of the system lie between Markham and Stouffville where individual well capacities in the upper system range from 25-50 gpm and where the aquifers are only slightly developed to date. The northern portions of the Markham systems contain permeable gravels that should be able to support individual well yields in the order of 300 to 400 gpm in many areas. Yields of this magnitude can meet most industrial and irrigation requirements and readily support moderate communal needs. In 1975, the total estimated water uses from the Markham aquifers collectively, including private supplies, totalled 1.7 mgd, which represents 56% of the recharge to the two systems. Of this 1.7 mgd use, approximately 1.5 mgd was withdrawn by the Markham municipal wells, and if these wells are abandoned, more than 90% of the aquifer potential of 3.0 mgd (Table 5) would be available for new development.

MANAGEMENT PLANNING

MANAGEMENT OBJECTIVES

Ground-water management objectives in the watershed relate to the protection and conservation of the quantity and quality of ground water for the benefit of domestic supplies, whether from individual rural wells or from communal municipal well systems, and for the maintenance of an adequate quantity of good quality ground-water discharge to streams for low-flow maintenance. These objectives are being adopted in principle by a number of agencies active in the basin, such as the Metro Toronto and Region Conservation Authority (MTRCA), the Ontario Ministry of Natural Resources (MNR), the Ontario Ministry of Agriculture and Food (OMAF) and the Ontario Ministry of the Environment (MOE). The water management policies of these agencies are documented, in part, by an interministerial Water Management Sub-Committee report regarding water management policies and goals for the Duffins Creek watershed (internal report).

The development and implementation of ground-water management objectives throughout the Duffins-Rouge basin are guided by the MOE on the basis of legislation defined in the Ontario Water Resources Act. Sections 31, 32, 33, 34 and 36 in this Act relate, in part, to the prevention of ground-water quality impairment. In addition, Section 37 of the OWR Act relates to the Ministry's function of regulating water takings through the Permit to Take Water system. The licensing of water-well drillers in the Province is regulated by Section 40 of the OWR Act and its associated Ontario Regulation 648/70, both of which provide the Ministry with a regulatory tool for standards application in the ground-water development industry. Regulation 648/70 also requires that all water-well drillers submit well logs to the Ministry, which subsequently form the basis for geologic and hydrologic data interpretations in order to determine ground-water availability in the basin.

In context of preliminary planning for the Toronto Area Airport Project (TAAP) site in the northern part of the Duffins Creek basin, TAAP undertook to determine in detail the existing ground-water conditions at the airport site. The objective was to foresee possible effects of construction on the ground-water regime and to devise methods of control to limit any serious effects likely to be caused by the construction activities. The terms of reference for the study also called for the development of a ground-water monitoring program to be operated for an initial period of five years to define ground-water quantity and quality changes caused by the operation of the airport. A report of this study was released in March of 1975 (Sobanski, 1975).

As part of its conceptual planning phase, the North Pickering Project (NPP) was committed to studying local ground-water conditions on the project site in order to identify specific areas where ground-water quality and/or quantity may be affected by urbanization. The study was carried out in 1975 and was designed to identify quantitatively streamflow dependence on ground water, to identify potential areas suitable for artificial ground-water recharge, and to develop an observation-well network for monitoring long-term trends in water levels and ground-water quality.

Much of the hydrogeologic data available through the present study were used by NPP during its conceptual planning stages. Specifically,

urban development locations have been situated, insofar as possible, in areas where there will likely be the least effect on the ground-water quantity and quality, and development within particular sites has been planned to minimize effects on ground water. To take advantage of highly permeable infiltration sites on the townsite, open parkland areas are planned in the area of exposed gravels near the southern limits of the townsite. The ground-water monitoring network established in 1975 will in time indicate what effects, if any, urban development may have on ground water. This type of monitoring should provide valuable data to assist future planning and assessment of the effects of urban development on ground water for other parts of the Province.

PRESENT MANAGEMENT METHODS

There are two basic administrative tools that provide the means for ground-water management in the basin:

1) Permit to Take Water program, and
2) land-use zoning.

In addition, there is also the concept of water-use zoning, but this means of control is more applicable to surface-water management than to ground water.

The Permit to Take Water program administered by the Ministry of the Environment is the single most important means of ground-water management in the basin. The program was developed as the result of legislation passed in 1961 that authorized the former Ontario Water Resources Commission (OWRC) to regulate water takings in the Province. Presently the legislation is defined in the OWR Act, Section 37, which deals specifically with permitting of water takings. The takings apply to both surface and ground water and exemptions are made for water withdrawals for domestic or farm purposes, and for fire fighting.

The permit system is a means of water management aimed at controlling and regulating water takings in order to promote its efficient development and beneficial use by residents of the Province. The system is also a valuable tool in the investigation and resolution of surface and ground-water interference cases by controlling large withdrawals of water in areas where interference is expected or observed.

Land-use zoning, because of its indirect control over ground-water resources, can be used only to a limited extent to plan for ground-water management. However in spite of its indirect means of application, the regional municipalities of York and Durham are both attempting to use it to full advantage to conserve and protect the resource wherever possible. This protection has been evident especially in trying to regulate land use on the Oak Ridges Moraine to maintain existing ground-water conditions in the area.

Major land-use zoning in the watershed relates to the Ontario Government's policy statement in May of 1970, regarding urban development centered around Toronto. The goals and objectives of the policy were outlined in a report entitled "Design for Development: Toronto-Centered Region". This report has subsequently formed the basis for a more recent report by the Central Ontario Lakeshore Urban Complex (COLUC) Task Force to the Advisory Committee on Urban and Regional Planning, dated December 1974. This latter report makes major recommendations regarding the preservation and protection of natural resources in the general area covering the Duffins-Rouge watershed, including the mini-

mization of "...the pollution of water..." as a main objective. By attempting to restrict urban sprawl through the TCR concept, conservation of water resources is achieved on a large scale. On a smaller scale inside the basin, ground-water management can be practiced by local municipalities and regional planning boards through the application of zoning by-laws that will promote water conservation and minimize ground-water pollution hazards.

GROUND-WATER QUANTITY MANAGEMENT CONCERNS

Ground-water quantity related problems in the basin have received generally less attention and concern by local residents than problems related to water quality. Probably one reason for this is that urban-related land development has historically affected water quality more noticeably than water quantity, and quantity changes have been more gradual and therefore less noticeable. However, ground-water quantity management is an obvious need as indicated by past interference problems in the Markham and Unionville areas, and in the central areas of the Rouge River basin where irrigation takings have led to ground-water interference complaints. This management is necessary in order to conserve an essential and economical resource so that optimum utilization can be made by a large proportion of the rural population in the watershed. The most obvious need for this management involves preventing local water-level interference problems with domestic wells, and a less obvious but a potentially more significant concern relates to the conservation of ground water in order to maintain streamflows during low-flow periods in the summer. This latter concern can be particularly significant in the Duffins Creek watershed and in the headwaters of Little Rouge Creek where a large proportion of streamflow consists of direct ground-water seepage and water obtained from flowing wells. The flowing well situation has been of particular local concern in the past and a more detailed discussion is warranted.

Flowing Wells

Although a number of areas exist in the basin where wells are likely to flow, there is primarily one large flowing well area in which the need for ground-water quantity conservation is obvious. In this regard, future conservation practices will be essential in the Lemonville-Stouffville area if the existing flowing conditions are to be maintained. There are presently about 130 flowing wells in the area, which in 1974 discharged an estimated 1.4 mgd (2.6 cfs) to streams flowing south out of the area. Most of these wells flow uncontrolled and provide water for local domestic supplies and recreational ponds. Some simply flow to the nearest watercourse with no specific use made of the water at the well site.

In most of the cases the perennial flow exceeds the quantity used and the excess represents a "wastage" of ground-water resources in the area. However considering that this excess provides water to streamflow, and in fact at many places makes up all of the streamflow, the "wastage" plays an essential role in maintaining streamflow in many areas. This points out the complex dual role of ground water in flowing well areas in general and in the Lemonville-Stouffville area specifically. Because of this dual role, it is important to realize that as more new

flowing wells are drilled, each releasing more ground water, a point will be reached where the wells will cease to flow. This in turn will reduce streamflow, or dry out some streams completely immediately downstream of the flowing wells, and serious curtailment could result to uses that have historically established a dependency on streamflow derived from flowing wells.

Another large area of recorded flowing wells is in the vicinity of Unionville, where water-well records on file with the Ministry indicate that 74 wells flowed at the time of construction. Some of these wells date back to 1955. However because of the uncontrolled flow from these wells, together with the large withdrawals of water by the Unionville and Markham municipal wells, only a few of the original wells continue to flow and only an occasional well drilled in the area in recent years has flowed. However, there is a chance that when the municipal wells cease to operate as the York-Durham water system is placed into operation, flowing conditions may be re-established at some time in the future in at least some wells. This could lead to a variety of obvious problems related to flooding, and this possible eventuality should be recognized and allowed for in management planning in the area.

Inadequacy of Supplies

With the exception of one general area in the southern part of the basin, private domestic quantities of ground water can be readily obtained in the basin. There are, however, 58 wells on record that have been classed as "dry" by the drillers (Map 13). The most prevalent reasons for these "dry" wells are that the wells have been terminated at depths too shallow to encounter an aquifer, or that the wrong drilling equipment was used. Many of the dry wells located in areas of the aquifers identified on maps 7 and 8 have been drilled too shallow to encounter the aquifers. Deeper drilling would probably have solved the problem. It should also be recognized that well-boring equipment has a definite depth limitation (approximately 60 feet maximum depth) whereas the commonly used rotary and cable and tool drilling equipment are usually capable of drilling deep enough to encounter any of the overburden aquifers in the basin.

Ground-water availability is generally poor in the southern part of the basin west and southwest of Pickering and Ajax where problems are often encountered in obtaining even domestic supplies. Inadequate supplies have been reported from both overburden and bedrock wells in the area, and the problem is often compounded by generally poor water quality when adequate supplies are found. Where the overburden is generally less than 50 feet thick in the area, large-diameter bored wells have been most successful in providing domestic supplies.

GROUND-WATER QUALITY MANAGEMENT CONCERNS

Considering the high degree of urban-related activity in the basin, there have been surprisingly few reported cases of pollution related to urban sources, and there are no known reported cases of significant contamination attributable to rural development and agricultural activities. Nevertheless, a number of significant potential sources exist, among the main ones being the hazards associated with sanitary landfill practices, pollution due to gasoline spills and leaks, road salts, nitrate contamination due to agricultural fertilizers, and

bacterial and nitrate contamination of well supplies by animal wastes and domestic septic systems. Contamination by the latter two sources can be locally significant but often is undetected and this is probably the reason why there have been no known problems. Figure 16 indicates the location of all operational sanitary landfill sites in the basin, as well as the locations and types of past reported contamination in the watershed.

Considerable public concern in the past has related to the location of municipal sanitary landfill sites around Metropolitan Toronto. Two of the four active sites shown on Figure 16 receive wastes almost exclusively from Toronto - the Liverpool Road and the Beare Road sites. In addition to solid wastes being disposed at both of the sites, the Beare Road site also receives some industrial liquid waste. The Brock Road North and South sites are in various stages of approval and will be used by Metropolitan Toronto in the future. The York Sanitation #4 site is utilized by Markham, Stouffville and Metropolitan Toronto, and the York Sanitation Aurora site services the Aurora and Newmarket district. York Sanitation #4 site is directly upgrade of the Stouffville municipal wells and considerable public concern was voiced by the residents of Stouffville regarding industrial wastes dumped at the site in the late 1960's. This practice has been discontinued since 1970 and the municipal wells have not been affected to date (1976).

There are only two known cases of gasoline contamination in the basin and only one complaint of well contamination attributed to highway salting. There are no known cases of contamination due to agricultural practices or septic systems; however, all these sources remain a potential for pollution of wells locally.

Areas generally most susceptible to ground-water pollution by gasoline, bacterial pollution associated with septic systems and animal wastes, salt contamination from highways, and nitrate contamination from agricultural fertilizers, can be evaluated on the basis of data shown on Map 16. These data consist of the depth to water table and the permeability of surface soils. On the basis of these two parameters, the hazards of contamination of mainly shallow wells and shallow ground-water systems can be compared from one area to another.

Most susceptible areas are generally those where the depth to water table is less than 10 feet and where the soil permeability is high. Such areas occur all along the lacustrine sand deposit associated with the Lake Iroquois shoreline and in the area of surface sands southwest of Unionville. Especially critical could be the area along the Lake Iroquois shoreline because ground water occurs primarily in shallow formations that have limited continuity. Any contamination reaching the water table here may result in the loss of water supplies with no reliable alternate sources readily available in the area. Contamination of shallow ground water around Unionville may not be as critical because the deep Unionville aquifers underlying the area offer a good alternate source that in all likelihood will not be affected by shallow contamination.

Future increased activity in the basin will undoubtedly lead to a greater potential for ground-water pollution. Apart from the obvious constraints that ground-water pollution places on water use, ground-water contamination can also lead to stream-water quality impairment. For this reason, the interrelationship between ground and stream water is an important fact to remember when allowing ground water in some areas to be contaminated by toxic substances; these substances may

Figure 16. Ground-water contamination and waste disposal sites (1976).

ultimately show up in stream water. However this does not happen in all instances, especially where the soil is poorly permeable and where the contamination of ground water is distant from a stream.

SUMMARY AND CONCLUSIONS

The report on the ground-water resources of the Duffins Creek-Rouge River drainage basins is the result of almost four years of intensive study in the rapidly developing area peripheral to Metropolitan Toronto. The report presents original data and associated analyses dealing in detail with overburden subsurface geologic investigations, aquifer delineations, ground-water recharge estimates and water quality analyses. Also inventoried are major ground-water uses. A number of major water management concerns are discussed.

The watershed covers an area of 268.5 square miles northeast of Toronto and is drained by the major streams of Duffins Creek and Rouge River, and by a number of small creeks, of which Petticoat Creek is the largest. Markham, Stouffville, Pickering, Unionville and Claremont are the largest urban centres in the basin. The basin is divided by the Regional Municipality of York in the west and the Regional Municipality of Durham in the east. The basin population was estimated to be 88,150 in 1975.

Shales of the Whitby and Georgian Bay formations underlie the watershed. These in turn are overlain by overburden deposits generally 200-300 feet thick throughout most of the basin. The surficial overburden deposits consist of tills, clays, silts, sands and/or gravels, with most of the basin being covering by till deposits attributed to the last Wisconsinan ice in the area. The Oak Ridges Moraine, a prominent physiographic high along the northern boundary of the basin, displays large areas in which sands and/or gravels are exposed on the surface. These areas allow a significant proportion of precipitation to infiltrate into the ground and provide recharge to ground water.

The stratigraphy of buried overburden deposits is tentatively correlated with the overburden formations mapped by Karrow (1967) in the Scarborough area to the south. The deposits are divided into four identifiable units that are illustrated in a schematic north-south cross section:

1. Upper Drift
2. Middle Drift
3. Interstadial Drift
4. Lower Drift

Each of the four units represents a major period of deposition, and except for the Lower Drift, each can be identified in most areas of the basin.

The Lower Drift consist wholly of a sand till which is tentatively correlated with the Illinoian York Till described by Karrow in the Scarborough area.

The Interstadial Drift consists largely of thick deposits of lacustrine silts, clays and deltaic sands correlated with the Scarborough and Thorncliffe formations. At some locations the two formations are separated by the Sunnybrook Till, but in most areas the till is missing. Where present, the till is a dense, clay or silt till with only a minor number of pebbles.

The Middle Drift consists primarily of tills deposited at the same time as the Meadowcliffe and Seminary tills in the Scarborough area, with usually thin interstratified deposits of sands, silts and clays. In the middle part of the basin significant ice-contact sands and gravels are thought to belong also to the Middle Drift unit. The composition of

tills in the unit is variable, ranging from a clay to a silt to a sand till in different areas and at different depths.

The Upper Drift consists mainly of the Halton Till with minor interbedded sands and/or gravels, some of which appear to be remnants of washed till. The Halton Till is a compact, silty sand till at most locations in the basin. Deposits of sand and gravel in the Oak Ridges Moraine are also part of the Upper Drift.

Hydrogeologic interpretations have relied primarily on existing water-well records available as of December 1974, and on detailed information gathered during an extensive test-drilling program in the basin carried out by the Ministry of the Environment. The test-drilling program involved three field seasons and resulted in 19 test holes, 17 of which were drilled to bedrock.

There are approximately 250 domestic wells in the basin that have been drilled into bedrock, but only a small proportion of these reportedly obtained water of unsable quantity for private domestic purposes. Bedrock is generally a poor source of water.

Overburden aquifers are the primary sources of water for domestic needs and some of these are capable of supplying large quantities of water. Fourteen major aquifer systems have been identified in the basin:

1. Oak Ridges
2,3. upper and lower Markham
4,5. upper and lower Unionville
6,7. upper and lower Victoria
8,9. upper and lower Brougham
10. Greenwood
11. Atha
12. Green River
13. Pickering
14. Cedar Grove

The largest complex of closely associated aquifers is referred to as the Oak Ridges aquifer system, which covers an area of approximately 86 square miles. Private domestic supplies are readily available from all drilled wells and most wells should be capable of yielding 50 gallons per minute (gpm) or more.

The upper and lower Markham aquifer systems consist of sand and/or gravel that are part of the Middle and Interstadial Drift units in the middle part of the basin. Both systems contain very coarse gravels in some areas and large municipal yields are being satisfied from these formations. Probable well yields will commonly range from 10-50 gpm, and it is likely that yields in excess of 100 gpm can be developed at many locations within each aquifer system.

The upper and lower Unionville aquifer systems are also part of the Middle and Interstadial Drift deposits of sands and gravels and large yields can be expected from certain areas in each system. Probable yields of 25-50 gpm will be most common in the upper system, and 10-25 gpm will be commonly available from the lower system.

Both of the Victoria aquifer systems are primarily in the Middle Drift unit where fine to coarse sands are the most common permeable materials. Potential yields from these systems are somewhat lower than from either the Markham or the Unionville systems, with most of the area in the upper system probably having yields in the range of 2-10 gpm, while yields from the lower system range from 10-25 gpm and from 25-50

gpm. Only isolated areas in either system can be expected to yield more than 50 gpm.

The upper and lower Brougham aquifer systems consists mainly of fine to medium sand, with the upper system being part of the Middle Drift unit and the lower system located in sands of the Interstadial Drift. Most common well yields in each system are in the range of 10-25 gpm, with substantially higher yields possible only from limited areas in each system.

The Greenwood aquifer system contains mainly fine to coarse sands of the Interstadial Drift unit, with gravels reported in some wells. Probable yields will commonly range from 10-25 gpm and higher yields are possible from local gravelly portions in the northern parts of the aquifer.

The rest of the four aquifers defined in the basin, the Atha, Green River, Pickering and Cedar Grove aquifers, are of relatively small importance because of the smaller areal extent and continuity of each.

The major horizontal ground-water movement components in both shallow and deep aquifers is toward the major streams and their tributaries. Duffins Creek valley has a pronounced effect on local shallow ground water and noticeably effects piezometric surfaces in the Greenwood and lower Brougham aquifer systems. Similarly, the Rouge River valley in the vicinity of Markham-Unionville and the valley of Bruce Creek influence piezometric surfaces in the Markham, Unionville and Victoria aquifer systems. The overall general direction of ground-water movement throughout the overburden is southward.

Each of the major aquifer systems are overlain by areas of upward and downward ground-water flow. Areas of upward flow occur generally in topographically low areas such as major stream valleys, and areas of downward flow are coincident with topographically high areas of land. The downward movement of ground water, i.e., recharge, into the defined aquifers was estimated to be 34.5 mgd, which is equivalent to a surface infiltration rate of 0.22 mgd per square mile over the 152.1 square mile area of downward movement in the 12 major aquifers. Applying this rate for the whole drainage basin of 268.5 square miles yields an estimated ground-water recharge value of 59.1 mgd for the basin. This is equivalent to an infiltration of 5.5 inches of precipitation. A recharge rate of 44.3 mgd (4.5 inches) was obtained through calculations of ground-water discharge to Duffins Creek and Rouge River. This estimate was based on established flow-duration curves at six streamflow gauging stations, and the assumption was made that ground-water discharge corresponded to a discharge equalled or exceeded 60% of the time.

The difference between the two estimates of recharge is probably attributable to the approximations and assumptions made in each of the two methods. However considering the amount of permeable materials on the surface in the basin, the estimated rate of 0.22 mgd per square mile is considered to be a more reasonable value.

Water-level fluctuations in the basin follow trends similar to most situations in southern Ontario. These trends show a high level of ground-water in the spring and low water stages in the late summer months. The decreases in storage represented by the annual water-level declines from the spring to the summer months are usually balance by equivalent increases in storage represented by water-level increases in the fall, winter and early spring months. During the most recent years, these ranges of fluctuations in ground-water storage have corresponded

to an approximate rate of change in storage of 44.3 mgd. However, average annual change in storage was assumed to be negligible.

Ground-water quality evaluations were based on a total of 44 samples; 2 samples are indicative of ground water in bedrock, and 42 samples were obtained from overburden sources. Both bedrock water samples are of the sodium-bicarbonate type. In addition to a predominance of high chloride values, bedrock waters are often reported by drillers to contain hydrogen sulphide gas, which makes the water in some cases unpotable. Most waters in overburden are of the calcium-bicarbonate type and generally of acceptable quality for domestic use. However, some of these waters tend to be very hard and contain undesireable concentrations of iron. High concentrations of nitrate are also present in a few wells, but this problem is generally not prevalent in the basin.

All ground waters from overburden sources are suitable for most irrigation practices in the basin, but waters from bedrock tend to have high sodium and salinity hazards and consequently are not recommended for irrigation except under special soil management conditions.

Ground water is an important source of supply for all the major water requirements in the basin, satisfying municipal, industrial, commercial, irrigation and private recreational needs. In 1975 these needs totalled approximately 6.5 mgd, which represents 44% of the amount allowed through permits issue by the Ministry of the Environment.

Municipal takings are centered around three municipal systems located within the basin at Markham, Unionville, and Stouffville, and around two systems operating just outside of the basin boundary at Thornhill and Oak Ridges. Withdrawals at sand and gravel operations are the primary industrial uses of ground water and most of these are located on the Oak Ridges Moraine north of Stouffville. Golf course irrigation is a common practice in the basin, and the irrigation of market crops is the primary agriculture use of ground water.

Reported water-supply interference cases in the basin have been relatively minor, and except for complaints attributed to municipal pumping at Markham and Unionville, the past cases have been of limited scope. Private domestic supply interference in the flowing well area near Lemonville has been of concern in the past and may pose future problems in the area.

Future ground-water use trends in the basin will be governed to a large extent by the York-Durham project, a provincially-funded sewage and water scheme north of Toronto. This project will extend Toronto's Lake Ontario water-supply system northward into the basin to service the Markham-Unionville and Ajax-Pickering areas in stages past 1985. As the integrated servicing scheme progresses, the reliance on ground water for municipal supplies will be reduced and existing ground-water sources at Markham and Unionville will probably be gradually phased out. Outside the area of the York-Durham scheme, ground water will continue to play an essential role in land-use development and water from all the identified aquifers in the basin will be primary in providing the necessary supplies.

Within future ground-water development practices, sound management related to quantity and quality maintenance will be essential. The most obvious concerns relate to preventing water-level interference in domestic wells and the Ministry's Permit To Take Water program is a major tool in preventing or resolving interference related complaints. Additionally,

the conservation of ground water for streamflow maintenance in certain parts of the basin must be recognized. In this context, future conservation of flowing wells in the Lemonville-Stouffville area will be essential to maintain the flowing conditions that in turn provide a substantial proportion of water to streamflow.

Primary water-quality concerns in the basin involve pollution potentials associated with sanitary landfill sites, and pollution due to gasoline spills and leaks, road salts, and nitrate and bacterial contamination derived from domestic septic systems. However none of these concerns have been of major extent in the past. Maps in the report showing soil permeability and depths to water table should assist in determining areas in which shallow ground water is most susceptible to contamination by hazards such as spills of gasoline or toxic liquids on the ground, or pollution due to domestic septic systems.

SELECTED BIBLIOGRAPHY

Bloyd, R.M. Jr., 1975, Summary appraisals of the nations's ground-water resources, Upper Mississippi region; U.S. Geol. Surv., Prof. Paper 813-B.

Caley, J.F., 1940, Palaeozoic geology of the Toronto-Hamilton area, Ontario; Geol. Surv. Can., Mem. 224.

Caley, J.F., Clark, T.H. and Owen, E.B., 1947, Ground-water resources of Pickering Township, Ontario County, Ontario; Can. Dept. Mines and Resources, Geol. Surv. Can., Water Supply Paper No.285.

Caley, J.F., Clark, T.H. and Owen, E.B, 1948, Ground-water resources of Markham Township, York County, Ontario; Can. Dept. Mines and Resources, Geol. Surv. Can., Water Supply Paper No.284.

Canada Department of the Environment, 1974, Proposed environmental guidelines for the construction and operation of the Pickering Airport.

Central Ontario Lakeshore Urban Complex Task Force, 1974, Central Ontario lakeshore urban complex; COLUC Task Force report.

Davis G.H., et al., 1959, Ground-water conditions and storage capacity in the San Jouquin Valley, California; U.S. Geol. Surv., Water Supply Paper 1469.

Davis, S.N., and De Wiest, R.J.W., 1966, Hydrogeology; John Wiley and Son Inc., New York.

Deane, R.E., 1950, Pleistocene geology of the Lake Simcoe district, Ontario; Geol. Surv. Can., Mem.256.

Dreimanis, A. and Terasmae, J., 1958, Stratigraphy of Wisconsin glacial deposits of Toronto area, Ontario; Proc. Geol. Assoc. Can., Vol.10, pp.119-235.

Gadd, N.R., 1950, Ground-water resources of Uxbridge Township, Ontario County, Ontario; Can. Dept. Mines and Tech. Surv., Geol. Surv. Can., Water Supply Paper No.307.

Gwyn, Q.H.J., and DiLabio, R.N.W., 1973, Quaternary geology of the Newmarket area, southern Ontario; Ont. Div. Mines, Prelim. Map P.836.

Haefeli, C.J., 1970, Regional groundwater flow between Lake Simcoe and Lake Ontario; Can. Dept. Energy, Mines Resources, Tech. Bull. No.23.

Hainstock, H.N., Owen, E.B. and Oaky, I.F., 1948, Ground-water resources of Scarborough Township, York County, Ontario; Can. Dept. Mines and Tech. Surv., Geol. Surv. Can., Water Supply Paper No.290.

Hainstock, H.N., Owen, E.B. and Caley, J.F., 1952, Ground-water resources of Whitchurch Township, York County, Ontario; Can. Dept. Mines and Tech. Surv., Geol. Surv. Can., Water Supply Paper No.320.

Hantush, M.S., 1957, Preliminary quantitative study of Rosewell ground-water reservoir, New Mexico; New Mexico Institute of Mining and Technology, Socorro, New Mexico.

Hantush, M.S., 1964, Hydraulics of wells; Advances in Hydroscience, Academic Press, Vol.1., pp.281-432.

Hewitt, D.F., and Karrow, P.F., 1963, Sand and gravel in southern Ontario; Ont. Dept. Mines, Ind. Min. Rept.11.

Hewitt, D.F., 1969, Industrial mineral resources of the Markham-Newmarket area; Ont. Dept. Mines, Ind. Min. Rept. 24.

Hewitt, D.F., 1972, Paleozoic geology of southern Ontario; Ont. Div. Mines, Geol. Rept. 105.

Hoffman, D.W., and Richards, N.R., 1955, Soil survey of York County; Can. Dept. Agric. and Ont. Agric. Coll., Rept. No.19.
Jacob, C.E., 1953, On the flow of water in an elastic artesian aquifer with notes on elasticity of the Lloyd Sand on Long Island, N.Y.; Ground Water Notes #8, U.S. Geol. Surv.
Karrow, P.F., 1967, Pleistocene geology of the Scarborough area; Ont. Dept. Mines., Geol. Rept. No.46.
Karrow, P.F., 1970, Pleistocene geology of the Thornhill area; Ont. Dept. Mines, Ind. Min. Rept. 32.
Karrow, P.F., 1974, Till stratigraphy of parts of south-western Ontario; Geol. Soc. Am. Bull., Vol.85, pp.761-768.
McKee, J.E., and Wolf, H.W., 1963, Water quality criteria; Calif. State Water Res. Control Brd., Publ. 3-A.
Kern, J.U., 1964, Aquifer performance test for Markham Ontario; International Water Supply Ltd.
Kerr, T.M., 1964, Report on pumping tests by Hengran Developments Ltd., Unionville area; Hydrology Consultants Ltd.
Kerr, T.M., 1966, Pumping test on a production well at the Town of Stouffville; Hydrology Consultants Ltd.
Mayhew, G.H., 1970, Analysis of test pumping of the wells at United Cooperatives, Ontario, Police Village of Claremont, Pickering Township, County of Ontario, Ontario; for J.D. Crowley and Associates.
Morrison, W.D., 1976, Report of a detailed urban terrain constraints survey of the urban area of the North Pickering Planning area; Hydrology Consultants Ltd., for the Ontario Ministry of Housing, North Pickering Development Corporation.
Morton, John, Ltd., 1974, Site investigation for route selection, York/Pickering trunk sewer Box Grove to KT; prepared for Marshall, Macklin, Monaghan Ltd., Don Mills.
Ogden, L., 1965, Estimating transmissibility with one drawdown; Ground Water, Vol.3, No.3, pp.51-54.
Olding, A.B., Wicklund, R.E., and Richards, N.R., (?) Soil survey of Ontario County; Can. Dept. Agric. and Ont. Agric. Coll., Rept. No.23.
Ontario Department of Planning and Development, 1956, Rouge, Duffins, Highland, Petticoat valley conservation report.
Ontario Ministry of the Environment, (?), York-Durham water and sewage service systems; MOE internal report.
Ontario Ministry of the Environment, 1974, Guidelines and criteria for water quality management in Ontario.
Ontario Ministry of Treasury, Economics and Intergovernmental Affairs (TEIGA), 1976, Municipal Directory.
Ontario Water Resources Commission, 1966, County of York, Central area regional study-final staff report; water supply and pollution control (internal report).
Ontario Water Resources Commission, 1968, Southern Ontario County and region water supply and pollution control study (internal report).
Ostry, R.C., (in preparation), Hydrogeology of the IFYGL Duffins Creek study area; Ont. Min. Envir., Water Res. Br., Water Resour. Rept.5c.
Rogers, D.P., Ostry, R.C. and Karrow, P.F., 1961, Metropolitan Toronto bedrock contours; Ont. Dept. Mines, Prelim. Map P-102.
Sobanski, A.A., 1975, Preliminary report on a ground-water study at the new Toronto airport site, Pickering, Ontario; Hydrology Consultants Ltd., prepared for Transport Canada, Toronto Area Airport Project.

Terasmae, J., 1960, A polynological study of Pleistocene interglacial beds at Toronto, Ontario; Geol. Surv. Can., Bull. 56, pp.24-40.

U.S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkali soils; U.S. Dept. Agric., Agric. Handbook No.60.

Watt, A.K., 1957, Pleistocene geology and ground-water resources of the Township of North York, York County; Ont. Dept. Mines, Vol.64, Part 7.

White, O.L., and Karrow, P.F., 1971, New evidence for Spencer's Laurentian River; Proc. 14th Conf. Great Lakes Res., pp.394-400.

Zeizel, A.J., Walton W.G., Sasman, R.T. and Prickett, T.A., 1962, Ground water resources of DuPage County, Illinois; Illinois State Water Survey and Geologic Survey, Co-operative Ground Water Report #2.

APPENDIX A

LOCATIONS AND DESCRIPTIONS OF GEOLOGIC AND GEOPHYSICAL WELL LOGS OF THE MINISTRY OF THE ENVIRONMENT TEST HOLES

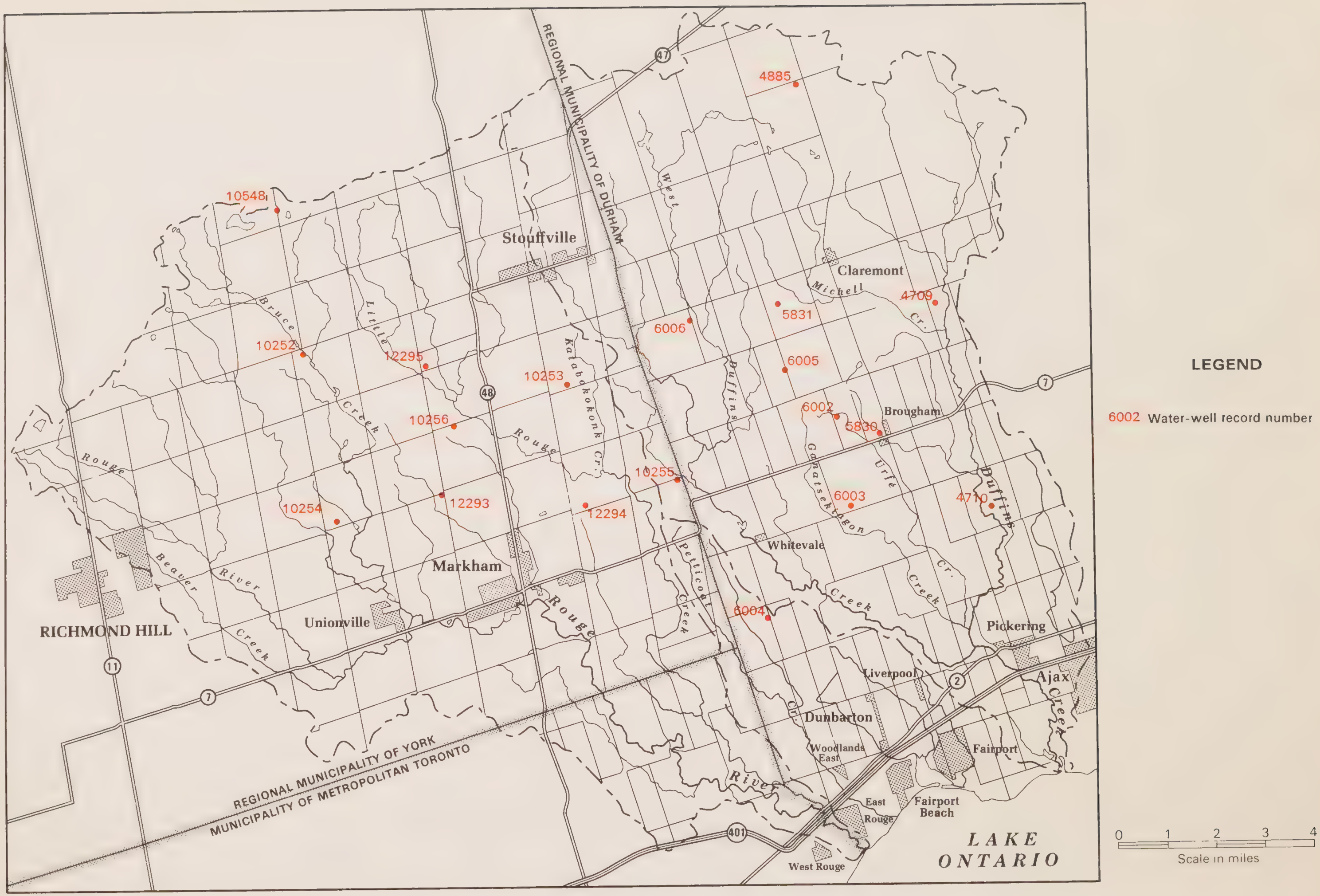
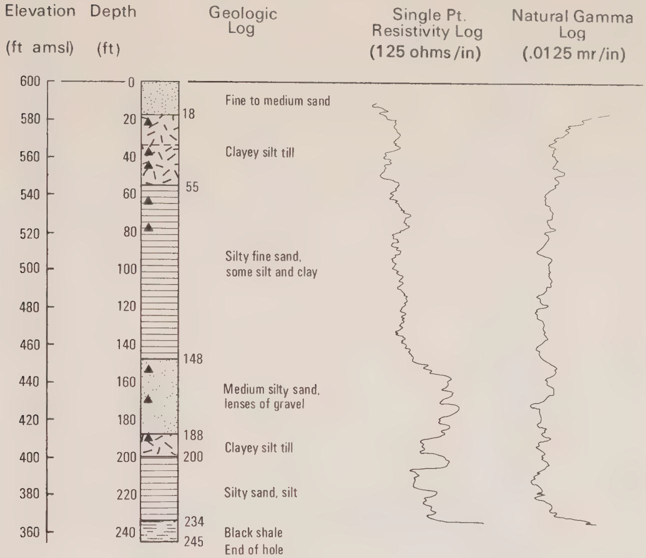


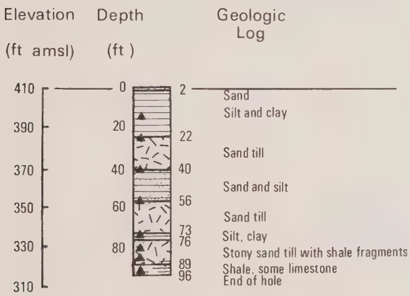
Figure 17. Locations of the Ministry of the Environment test holes.

Figure 18. Geologic and geophysical well logs of the Ministry of the Enviroment test holes.

TEST HOLE 4709* DUFFINS-ROUGE BASIN

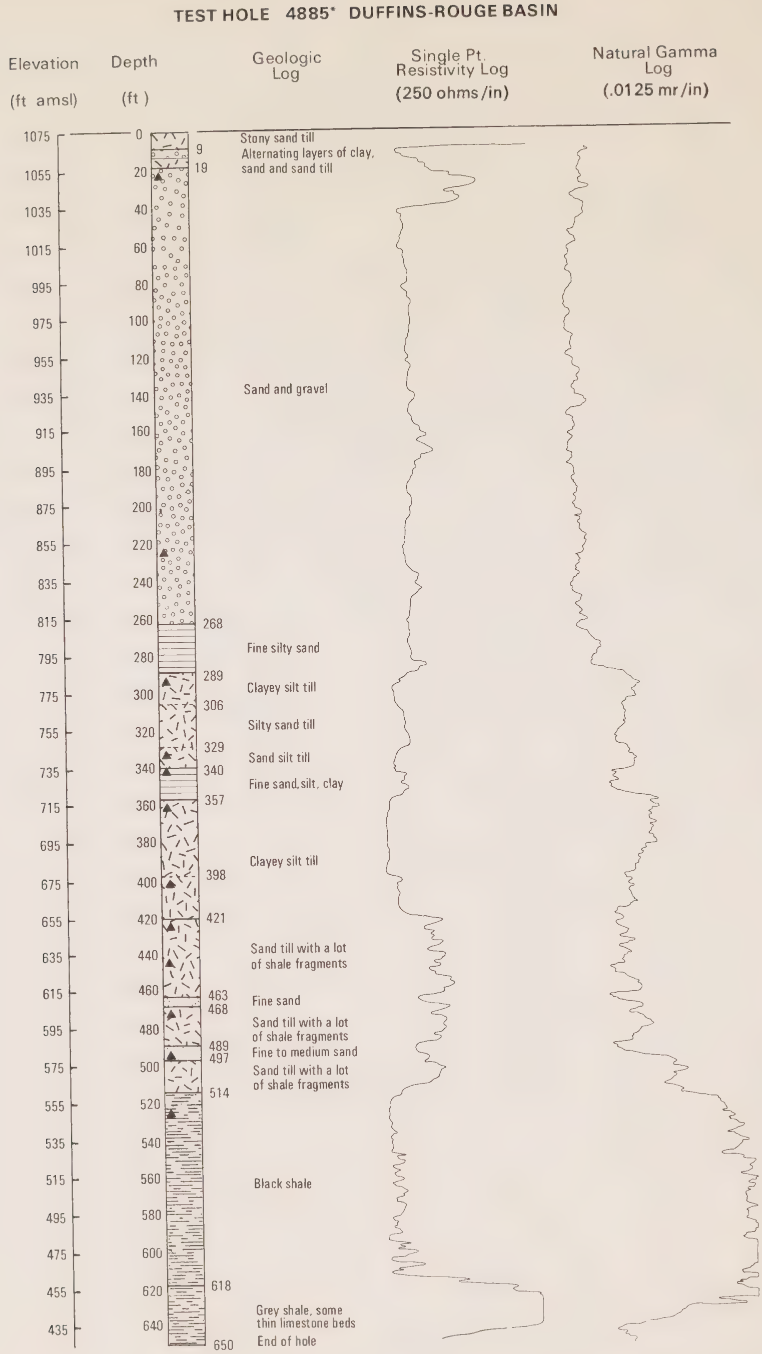


TEST HOLE 4710* DUFFINS-ROUGE BASIN



* Location shown on Map 6
▲ Split spoon sample

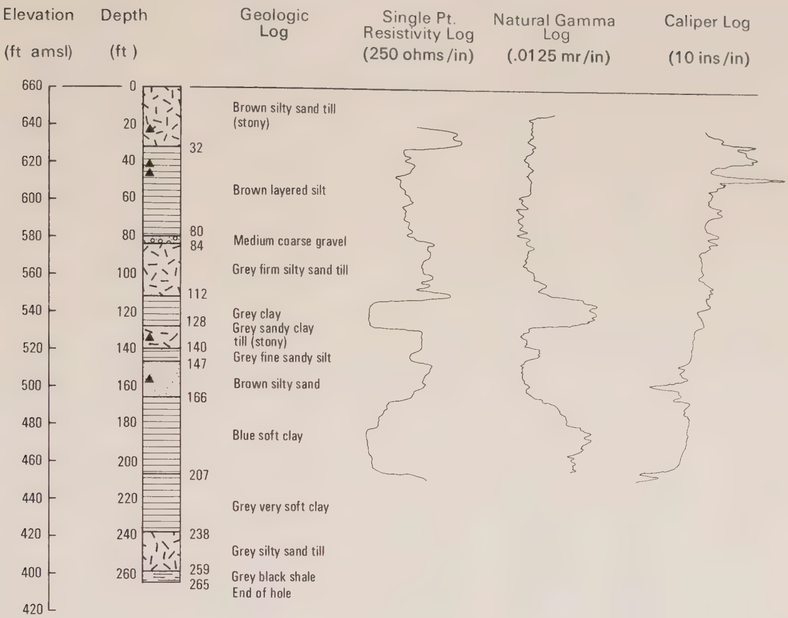
Figure 18 (continued)



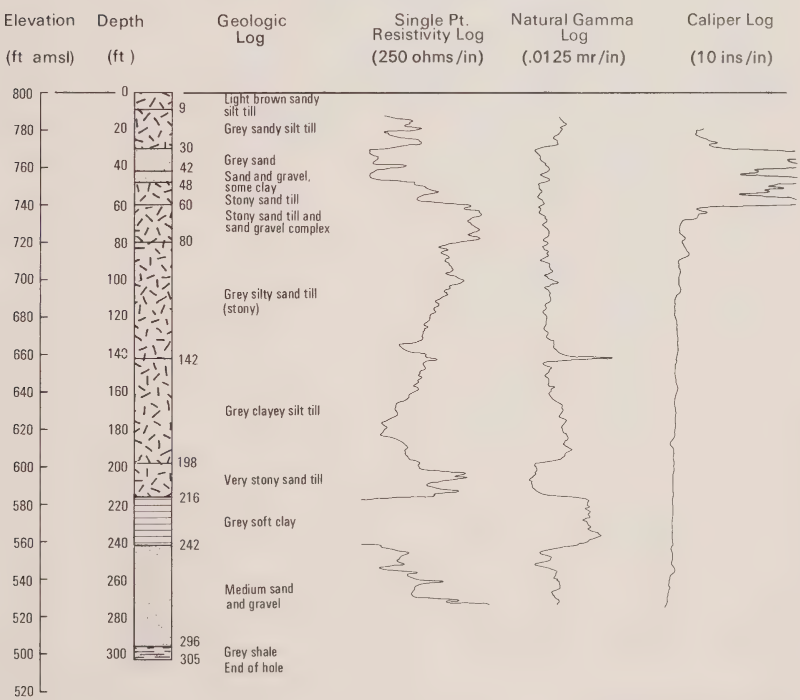
* Location shown on Map 6
▲ Split spoon sample

Figure 18 (continued)

TEST HOLE 5830* DUFFINS-ROUGE BASIN



TEST HOLE 5831* DUFFINS-ROUGE BASIN

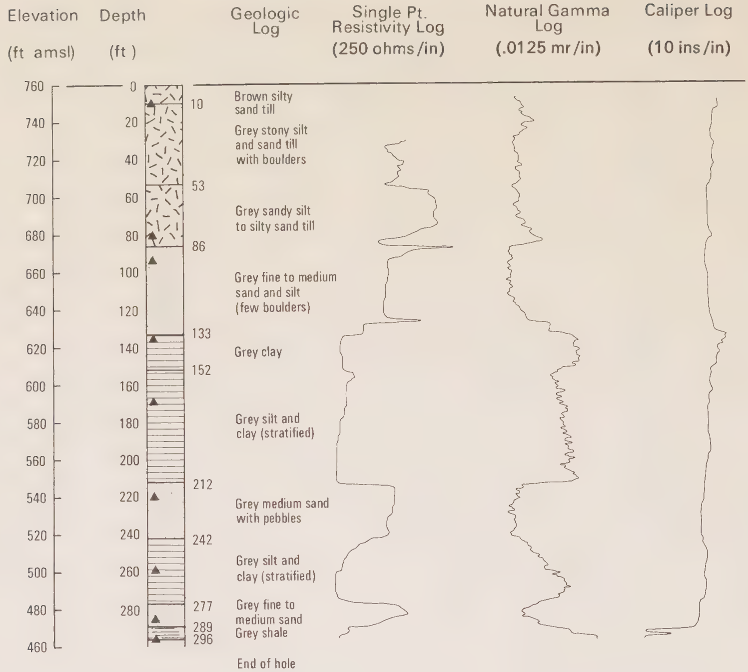


* Location shown on Map 6

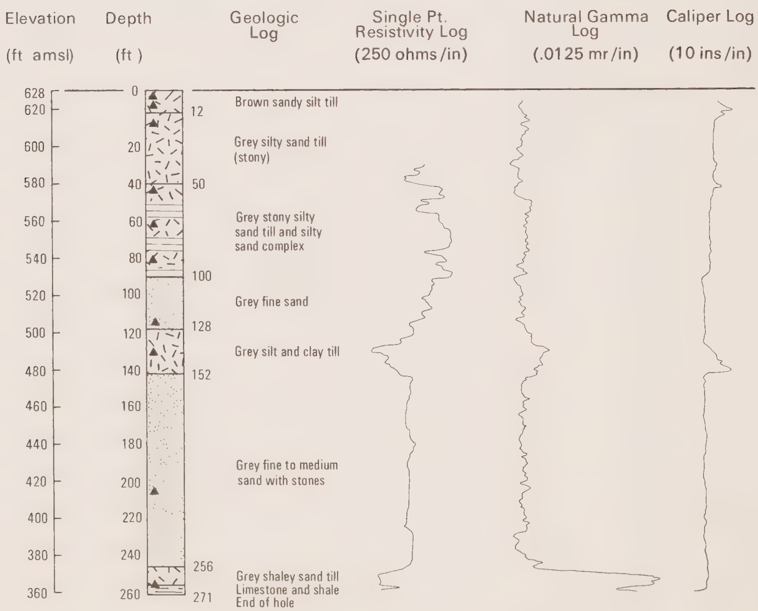
▲ Split spoon sample

Figure 18 (continued)

TEST HOLE 6002* DUFFINS-ROUGE BASIN



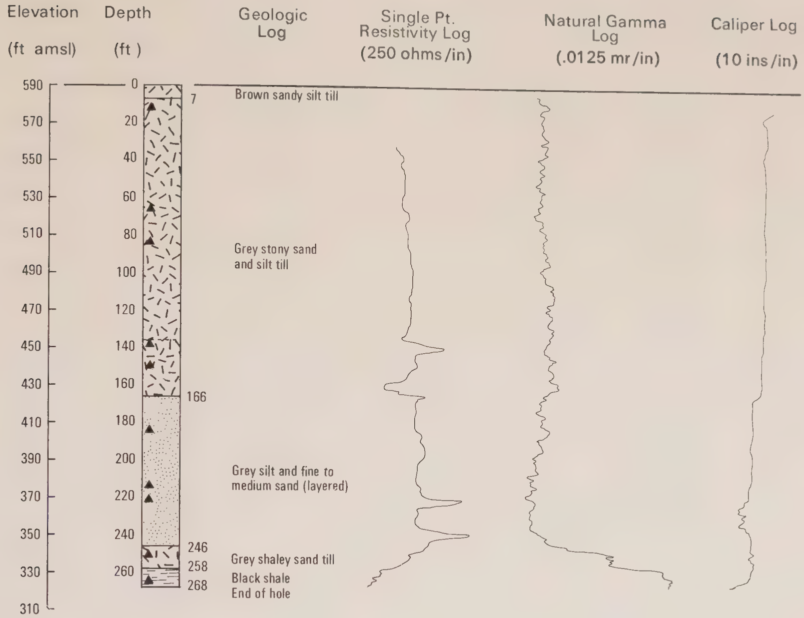
TEST HOLE 6003* DUFFINS-ROUGE BASIN



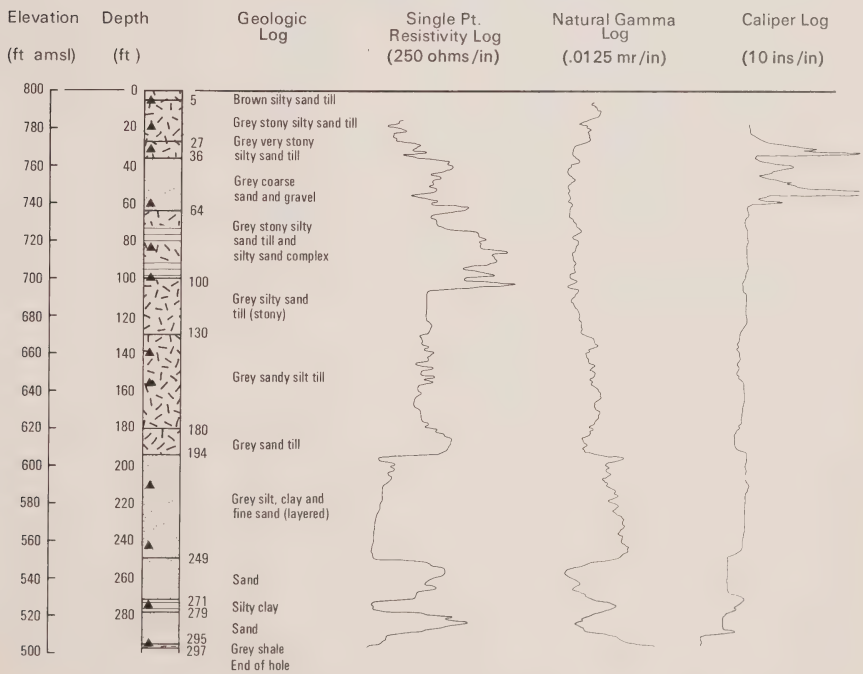
* Location shown on Map 6
▲ Split spoon sample

Figure 18 (continued)

TEST HOLE 6004* DUFFINS-ROUGE BASIN



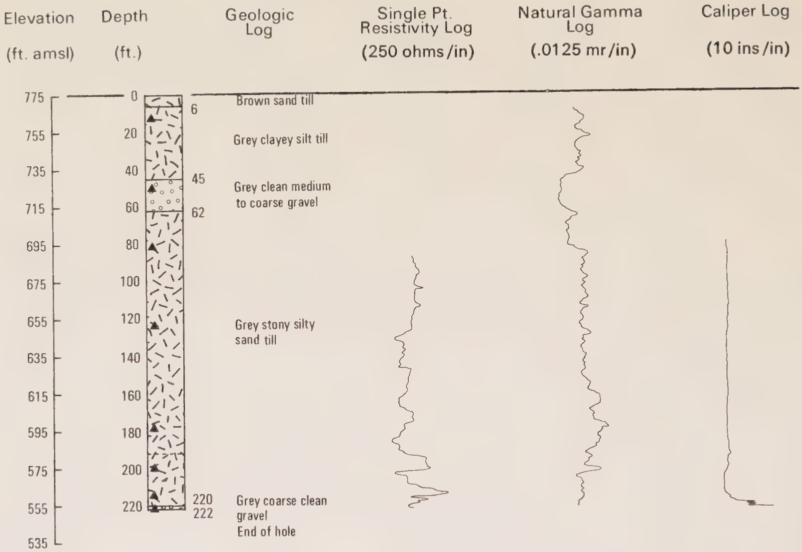
TEST HOLE 6005* DUFFINS-ROUGE BASIN



* Location shown on Map 6
▲ Split spoon sample

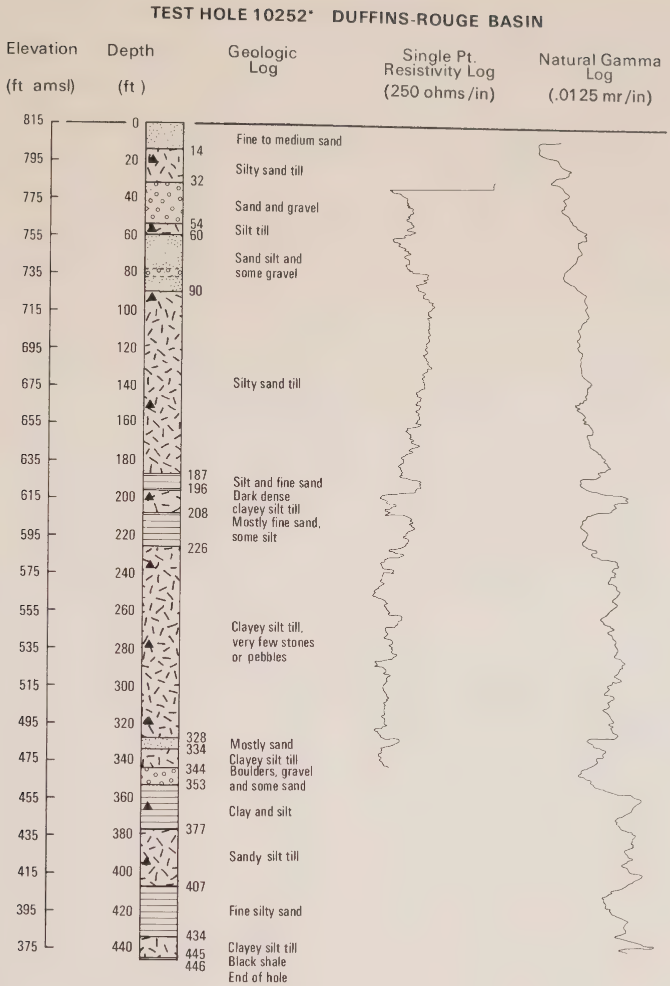
Figure 18 (continued)

TEST HOLE 6006* DUFFINS-ROUGE BASIN



* Location shown on Map 6
▲ Split spoon sample

Figure 18 (continued)

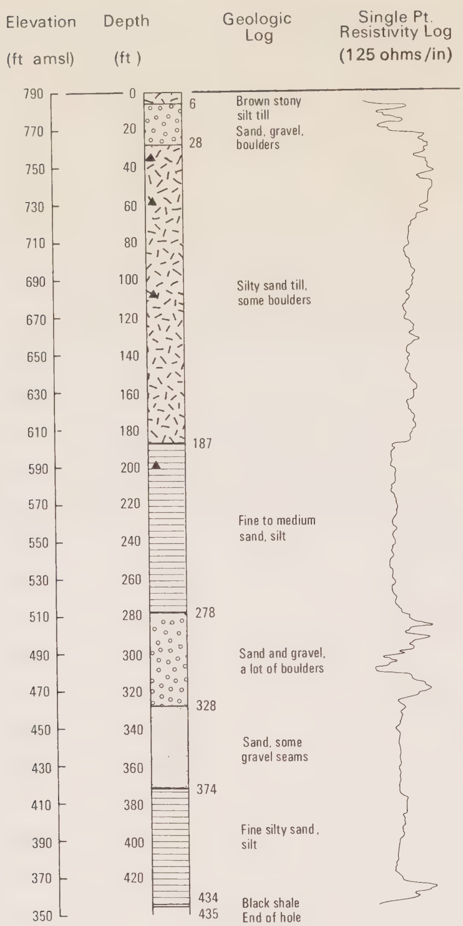


* Location shown on Map 6

▲ Split spoon sample

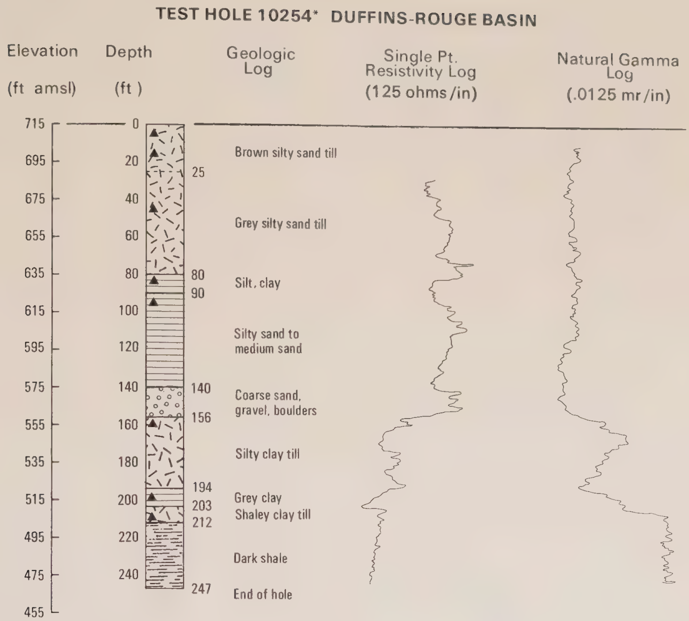
Figure 18 (continued)

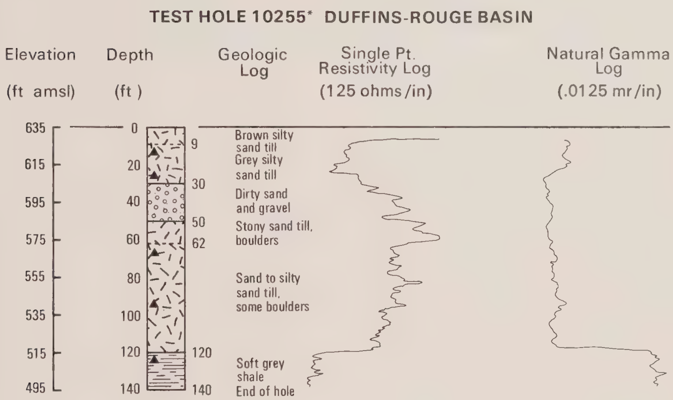
TEST HOLE 10253* DUFFINS-ROUGE BASIN



* Location shown on Map 6
▲ Split spoon sample

Figure 18 (continued)

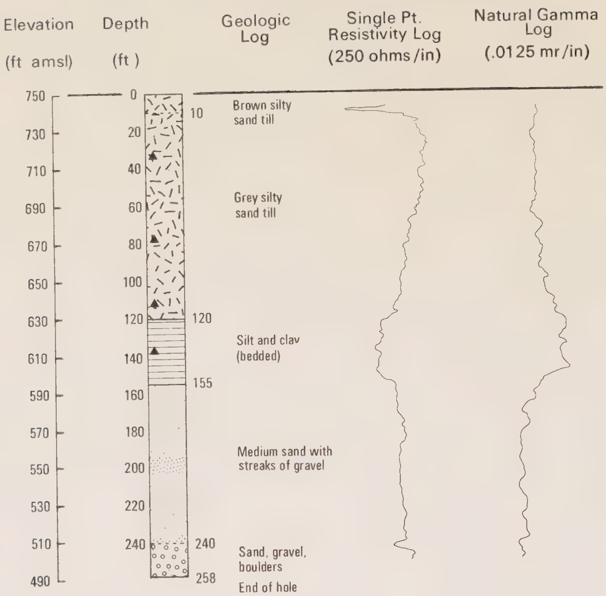




* Location shown on Map 6
▲ Split spoon sample

Figure 18 (continued)

TEST HOLE 10256* DUFFINS-ROUGE BASIN



* Location shown on Map 6
▲ Split spoon sample

Figure 18 (continued)

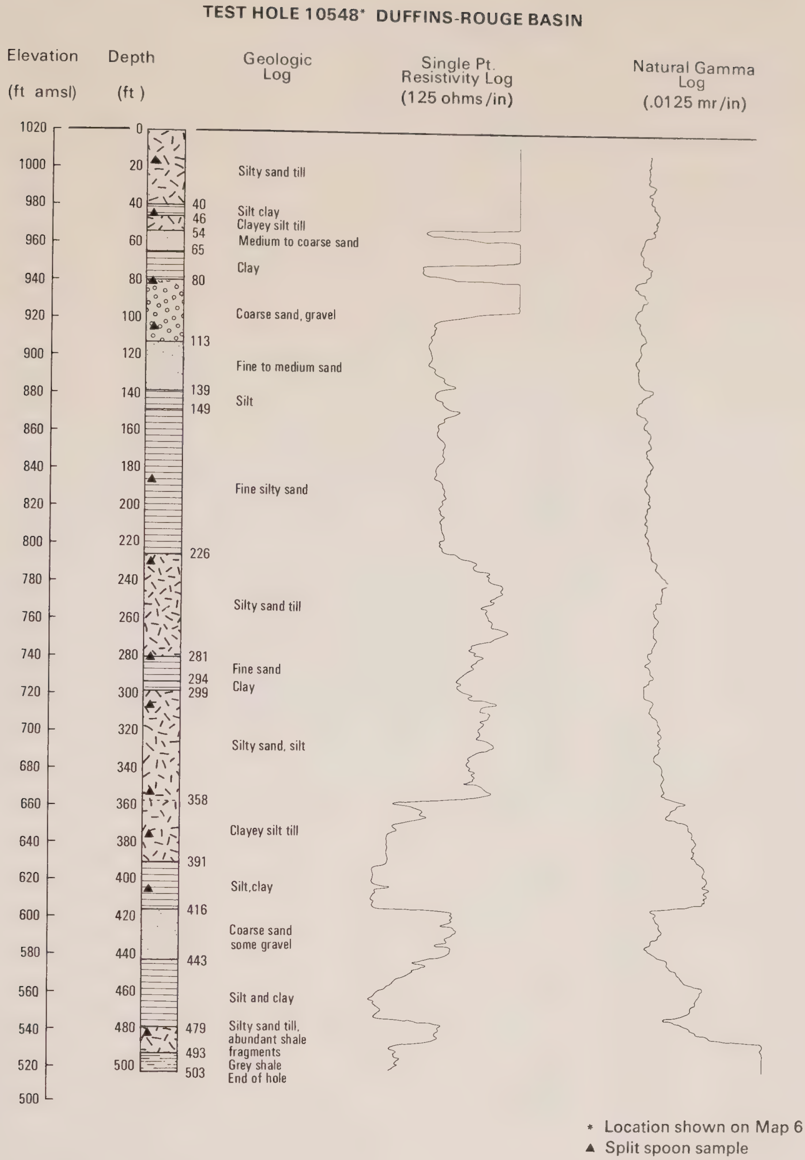
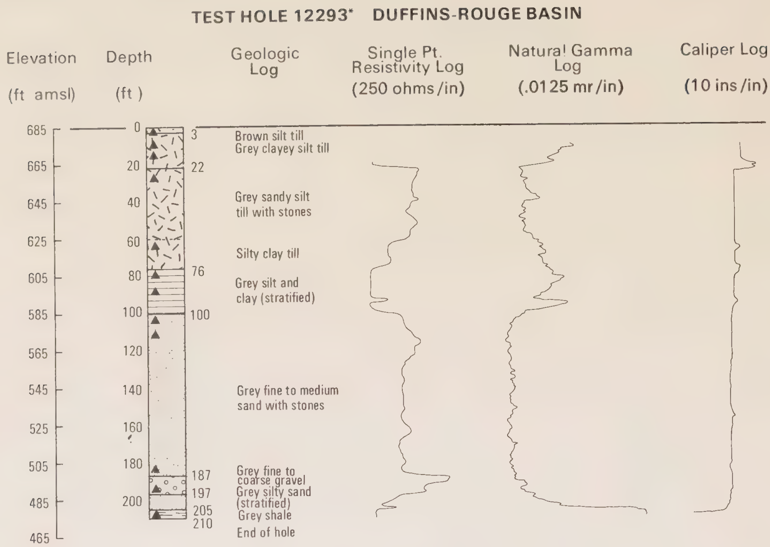
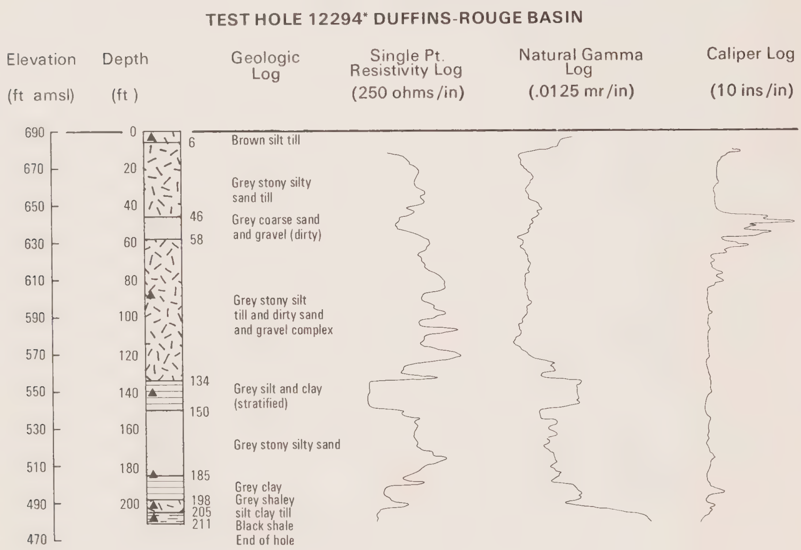


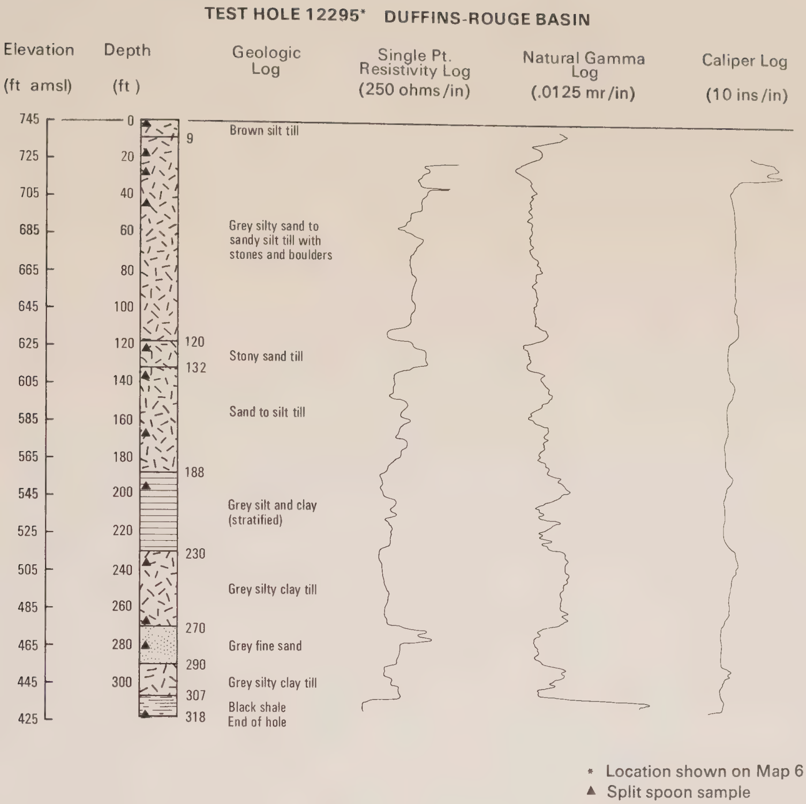
Figure 18 (continued)





* Location shown on Map 6
▲ Split spoon sample

Figure 18 (continued)



APPENDIX B

ANALYSES OF TILL SAMPLES

APPENDIX B

TABLE 9. Analyses of Till Samples

		Grain-Size Analysis					Pebble Count				
Sample No.*	Description	Clay (%)	Silt (%)	Sand (+ gravel) (%)	Calcite/ Dolomite Ratio	Number of Pebbles	lst (%)	dol (%)	sh (%)	ss (%)	xl (%)
4709 - 20	clayey silt till	33	39	28	3.1	95	84	2	3	2	9
- 38	clayey silt "	40	54	6	1.6	13	92	0	0	0	8
- 41	clayey silt "	40	50	10	1.9	41	61	7	7	3	22
-190	silty sand "	30	43	27	1.1	-	-	-	-	-	-
4710 - 24	silty sand "	22	38	40	1.6	45	62	4	27	0	7
- 56	silty sand "	10	31	37+22	1.5	100+	64	6	18	0	12
- 79	silty sand (stny) till	7	21	31+49	3.9	100+	86	1	0	0	13
- 85	silty sand (stny) till	15	20	36+29	.87	100+	20	0	80	0	0
10252 - 19	sandy silt till	20	39	41	3.5	30	65	5	10	0	20
- 57	clayey silt "	26	52	22	3.2	11	100	0	0	0	0
- 90	silty sand "	18	36	46	2.9	8	50	12	0	0	38
-155	silty sand "	19	36	45	2.5	21	81	0	0	0	19
-200	clayey silt "	37	49	14	2.1	3	100	0	0	0	0
-234	clayey silt "	37	61	2	2.4	-	-	-	-	-	-
-279	clayey silt "	32	59	9	2.0	-	-	-	-	-	-
-320	clayey silt "	33	50	17	2.1	6	100	0	0	0	0
-396	sandy silt till	26	43	31	2.9	39	51	8	28	0	13
10254 - 6	silty sand till	22	37	41	11.2	10	80	10	10	0	0
- 14	silty sand "	14	40	46	4.3	10	60	0	0	0	40
- 50	silty sand "	12	41	47	3.3	33	79	3	0	0	18
-160	silty clay till	42	35	23	3.0	10	80	0	10	0	10
10255 - 13	silty sand till	24	32	44	4.4	18	78	0	11	0	11
- 25	silty sand "	18	36	46	3.4	36	67	8	14	0	11
- 65	stony sand "	8	10	82	10.9	100+	71	4	0	0	25
- 95	silty sand (stny) till	16	42	48	3.8	15	80	13	0	0	7
10256 - 35	silty sand till	13	39	48	5.1	31	91	0	0	0	9
- 80	silty sand "	16	36	50	-	41	71	0	2	0	27
-115	silty clay till	38	37	25	6.9	3	100	0	0	0	0

Table 9 continued

Sample No.*	Description	Grain-Size Analysis Clay (%)	Silt (%)	Sand (+ gravel) (%)	Calcite/ Dolomite Ratio	Number of Pebbles	Pebble Count lst (%)	dol (%)	sh (%)	ss (%)	xl (%)
6003 - 15	silty sand (stny) till	23	29	38+10	6.9	30	90	3	0	0	7
- 56	silty sand (stny) "	14	30	46+10	5.2	23	74	0	0	0	26
-142	silty clay till	38	38	24	3.7	12	92	0	0	0	8
-266	very stny sand till	9	11	28+52	0.8	67	0	0	100	0	0
6003B- 75	silty sand till	17	33	50	4.4	21	76	5	0	0	19
- 95	silty sand "	10	24	66	4.2	15	80	0	0	0	20
6002 - 10	silty sand till	24	32	44	7.5	20	80	0	0	0	20
- 80	sandy silt till	28	38	34	3.1	11	82	18	0	0	0
6005 - 35	silty sand (stny) till	11	25	44+20	4.6	38	92	3	0	0	5
- 85	silty sand till	8	41	51	4.1	8	88	0	0	0	12
-100	silty sand (stny) till	11	26	41+22	6.9	30	80	0	0	0	11
-140	sandy silt till	23	44	33	1.9	9	56	33	0	0	11
-155	sandy silt till	31	37	32	3.1	13	85	15	0	0	0
6004 - 10	clayey sand till	32	30	38	6.3	19	84	0	0	0	16
- 65	silty sand "	24	30	32+14	5.8	77	71	4	0	0	25
- 85	silty sand (stny) till	27	30	34+9	6.9	71	82	0	0	0	18
-140	silty sand till	17	38	45	3.3	3	67	0	0	0	33
-152	silty sand "	26	33	41	4.2	24	67	0	0	4	29
-251	sand till (stny shale)	16	14	70	1.4	95	16	3	80	0	1
6006 -1-12	silty clay till	50	31	19	9.7	12	58	17	8	0	17
-3-80	silty sand (stny) till	22	30	34+14	6.0	86	94	0	0	0	6
-4-127	silty sand till	21	29	34+16	6.0	58	84	4	0	0	12
-5-178	silty sand "	17	28	46+9	6.8	13	85	7	0	0	8
-6-217	silty sand till	7	12	33+42	4.0	163	86	2	0	2	10

* first number refers to test hole shown on Figure 17; second number indicates depth of sample; e.g. 4709-20; 4709 is test hole number and 20 is the depth at which the sample was obtained (feet)

Table 9 continued

Sample No.*	Description	Grain-Size Analysis Clay (%)	Silt (%)	Sand (+ gravel) (%)	Calcite/ Dolomite Ratio	Number of Pebbles	Pebble Count lst (%)	dol (%)	sh (%)	ss (%)	xl (%)
10253 - 30	silty sand till	14	43	43	-	42	74	5	0	0	21
- 55	silty sand "	15	36	49	-	39	71	4	0	0	25
-110	silty sand till	14	32	54	3.6	39	90	0	0	0	10
10548 - 18	silty sand till	13	31	56	9.0						
- 45	clayey silt "	32	49	19	5.1						
-228	silty sand (stny) till	22	35	43	5.0						
-305	silty sand (stny) "	11	38	51	4.2						
-356	sandy silt till	14	44	42	3.2						
-373	clayey silt "	30	41	29	2.9						
-480	silty sand (stny) till	22	27	51	4.2						
4885 -295	clayey silt till	30	45	25	4.5						
-332	sandy silt "	20	53	27	2.0						
-364	clayey silt "	31	48	21	1.5						
-402	silty sand "	31	39	40	6.5						
-429	silty sand (stny) till	16	30	54	5.4						
-445	silty sand (stny) "	9	21	70	6.6						
-474	silty sand (stny) till	10	17	73	4.8						
4830 - 25	silty sand till	16	33	51	7.4						
-132	sandy clay till	54	21	25	3.5						
12293 - 25	silty sand till	24	31	45	5.8	19	89	5	0	0	6
- 65	silty clay till	44	30	26	5.4	11	73	27	0	0	0
12295 - 19	silty sand (stny) till	10	26	64	5.1	29	79	7	0	0	14
- 51	silty sand till	26	31	33	5.5	20	80	5	0	0	-
-119	silty sand "	18	23	39+20	3.7	31	74	0	0	3	23
-234	silty clay till	42	40	18	3.0	0	0	0	0	0	0
12294 - 21	silty sand till	15	31	40+14	4.9	23	83	0	0	0	17
-201	silty clay till	42	43	15	2.5	5	0	0	100	0	0

APPENDIX C

MINISTRY OF THE ENVIRONMENT

WATER-WELL RECORD FORM

Ministry of the Environment

Ontario

The Ontario Water Resources Act

WATER WELL RECORD

1. PRINT ONLY IN SPACES PROVIDED
2. CHECK ☒ CORRECT BOX WHERE APPLICABLE

COUNTY OR DISTRICT	TOWNSHIP, BOROUGH, CITY, TOWN, VILLAGE	CON., BLOCK, TRACT, SURVEY, ETC	LOT
OWNER (SURNAME FIRST)	ADDRESS	DATE COMPLETED DAY ___ MO ___ YR. ___	

LOG OF OVERBURDEN AND BEDROCK MATERIALS (SEE INSTRUCTIONS)

GENERAL COLOUR	MOST COMMON MATERIAL	OTHER MATERIALS	GENERAL DESCRIPTION	DEPTH - FEET FROM	TO

WATER RECORD

WATER FOUND AT - FEET	KIND OF WATER
	☐ FRESH ☐ SULPHUR ☐ SALTY ☐ MINERAL
	☐ FRESH ☐ SULPHUR ☐ SALTY ☐ MINERAL
	☐ FRESH ☐ SULPHUR ☐ SALTY ☐ MINERAL
	☐ FRESH ☐ SULPHUR ☐ SALTY ☐ MINERAL
	☐ FRESH ☐ SULPHUR ☐ SALTY ☐ MINERAL

CASING & OPEN HOLE RECORD

INSIDE DIAM INCHES	MATERIAL	WALL THICKNESS INCHES	DEPTH - FEET FROM	TO
	☐ STEEL ☐ GALVANIZED ☐ CONCRETE ☐ OPEN HOLE			
	☐ STEEL ☐ GALVANIZED ☐ CONCRETE ☐ OPEN HOLE			
	☐ STEEL ☐ GALVANIZED ☐ CONCRETE ☐ OPEN HOLE			

SCREEN

SIZE(S) OF OPENING (SLOT NO.)	DIAMETER INCHES	LENGTH FEET
MATERIAL AND TYPE	DEPTH TO TOP OF SCREEN FEET	

PLUGGING & SEALING RECORD

DEPTH SET AT - FEET FROM	TO	MATERIAL AND TYPE (CEMENT GROUT LEAD PACKER, ETC.)

PUMPING TEST

PUMPING TEST METHOD ☐ PUMP ☐ BAILER	PUMPING RATE GPM	DURATION OF PUMPING ___ HOURS ___ MINS
STATIC LEVEL FEET	WATER LEVEL END OF PUMPING FEET	WATER LEVELS DURING ☐ PUMPING ☐ RECOVERY: 15 MINUTES FEET; 30 MINUTES FEET; 45 MINUTES FEET; 60 MINUTES FEET
IF FLOWING GIVE RATE GPM	PUMP INTAKE SET AT FEET	WATER AT END OF TEST ☐ CLEAR ☐ CLOUDY
RECOMMENDED PUMP TYPE ☐ SHALLOW ☐ DEEP	RECOMMENDED PUMP SETTING FEET	RECOMMENDED PUMPING RATE GPM

LOCATION OF WELL

IN DIAGRAM BELOW SHOW DISTANCES OF WELL FROM ROAD AND LOT LINE. INDICATE NORTH BY ARROW.

DRILLERS REMARKS

FINAL STATUS OF WELL	☐ WATER SUPPLY ☐ OBSERVATION WELL ☐ TEST HOLE ☐ RECHARGE WELL ☐ ABANDONED, INSUFFICIENT SUPPLY ☐ ABANDONED POOR QUALITY ☐ UNFINISHED
WATER USE	☐ DOMESTIC ☐ STOCK ☐ IRRIGATION ☐ INDUSTRIAL ☐ OTHER ☐ COMMERCIAL ☐ MUNICIPAL ☐ PUBLIC SUPPLY ☐ COOLING OR AIR CONDITIONING ☐ NOT USED
METHOD OF DRILLING	☐ CABLE TOOL ☐ ROTARY (CONVENTIONAL) ☐ ROTARY (REVERSE) ☐ ROTARY (AIR) ☐ AIR PERCUSSION ☐ BORING ☐ DIAMOND ☐ JETTING ☐ DRIVING

CONTRACTOR

NAME OF WELL CONTRACTOR	LICENCE NUMBER
ADDRESS	
NAME OF DRILLER OR BORER	LICENCE NUMBER
SIGNATURE OF CONTRACTOR	SUBMISSION DATE DAY ___ MO ___ YR ___

OFFICE USE ONLY

CONTRACTOR'S COPY

FORM NO. 0506—4—77

Figure 19. Ministry of the Environment Water Well Record form.

APPENDIX D

1. OGDEN (1965) FORMULA FOR ESTIMATING TRANSMISSIBILITY
2. JACOB (1953) MODIFIED NONLEAKY ARTESIAN FORMULAE
3. HANTUSH (1964) LEAKY ARTESIAN FORMULAE - UNSTEADY STATE

1. Ogden (1965) Formula for estimating transmissibility from one measurement of drawdown in the pumped well.

$$\mu\ (W(\mu)) = \frac{1.56\ r^2 Ss}{114.6\ Qt} \quad ; \quad T = \frac{1.56\ r^2 S}{\mu t}$$

$W(\mu)$ = well function
s = reported drawdown in pumped well (ft)
Q = constant pumping rate (gpm)
T = transmissibility (gpd/ft)
r = radius of pumped well (ft)
S = coefficient of storage
t = duration of pumping test (days)

$$\mu = \frac{1.56 r^2 S}{Tt}$$

The coefficient of storage for artesian aquifers was assumed to be 5×10^{-4}, and the specific yield for water-table aquifers was assumed to be 0.1. Values of $\mu(W(\mu))$ and corresponding μ's were estimated from graph and/or table given by Ogden (1965, p.52).

2. Jacob (1953) Modified Nonleaky Artesian Formulae

(a) (drawdown-time curve for one observation well)

$$T = \frac{264Q}{\Delta S} \quad ; \qquad S = \frac{0.3T\ t_o}{r^2}$$

T = transmissibility (gpd/ft)
Q = discharge (gpm)
ΔS = drawdown per log cycle (ft)
t_o = time at zero drawdown (days)
r = distance from pumped well to observation well (ft).

(b) (drawdown - distance curve for more than one observation well)

$$T = \frac{528Q}{\Delta S} \quad ; \qquad S = \frac{0.3Tt}{r_o^2}$$

t = time after pumping started (days)
r_o = distance at zero drawdown (ft)

3. Hantush (1964) Formulae for Leaky Artesian Aquifer - Unsteady State. ("Hantush Inflection - Point Method")

This method utilizes semilog drawdown-time curves for one observation well in which the procedure is as follows (Hantush 1964 p.417):

(1) estimate s_m from curve in which drawdown is in feet and time in minutes
(2) calculate s_i from

$$s_i = 0.5 s_m$$

(3) locate s_i on curve - this is "inflection point" (IP); determine corresponding value of t_i

(4) determine m_i of curve at IP

(5) calculate the quantity $\frac{2.3 s_i}{m_i}$, and

(a) obtain corresponding value of r/B from a table/graph of f(r/B), or

(b) if $\frac{2.3 s_i}{m_i} > 4.77$, obtain B/r using:

$$\log_{10} \frac{(2B)}{r} = 0.251 + \frac{s_i}{m_i}$$ and calculate B.

(6) Calculate T,S, $\frac{K'}{b'}$ using

(a) $T = \frac{264}{m_i} Qe^{-r/B}$ <u>or</u> $T = \frac{114.6Q\, K_o(r/B)}{s_i}$

(b) $S = \frac{Tt_i\,(r/2B)}{1.56\, r^2}$

(c) $\frac{K'}{b'} = \frac{T}{B^2}$

s_m = estimated maximum (steady-state) drawdown (ft)

s_i = drawdown at inflection point (ft)

t_i = time corresponding to s_i (days)

m_i = slope at inflection point

r = distance from observation to pumped well (ft)

B = leakage factor (ft)

$K_o(r/B)$ = function (found in tables)

Q = discharge (gpm)

T = transmissibility (gpd/ft)

S = coefficient of storage

$\frac{K'}{b'}$ = coefficient of leakage (gpd/ft^3)

APPENDIX E

CHEMICAL ANALYSES OF GROUND-WATER SAMPLES

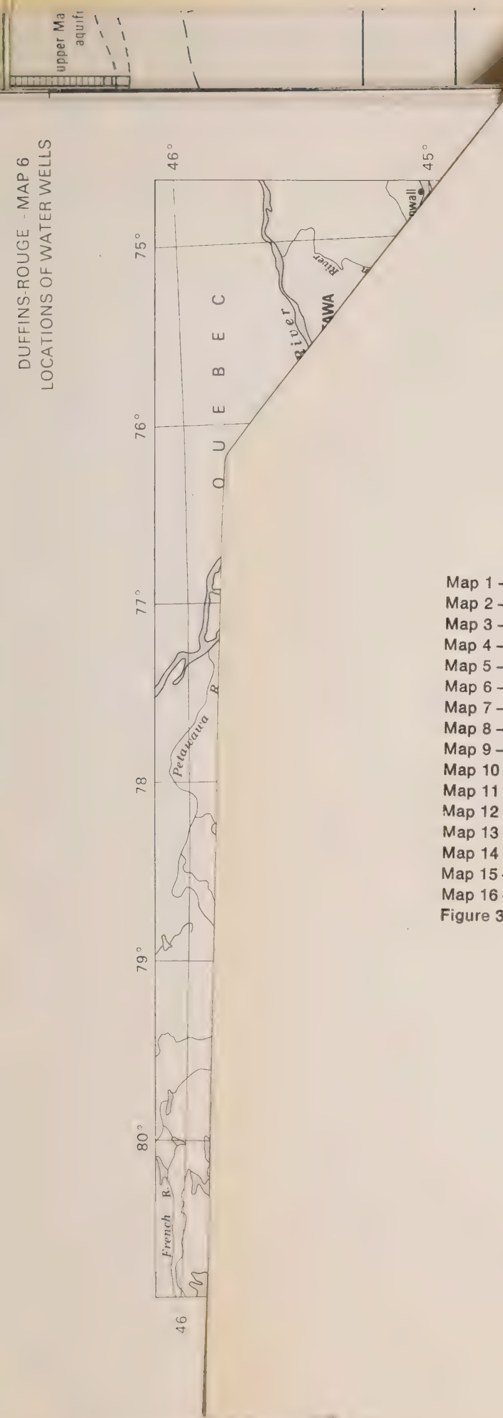
Table 10. Chemical Analyses of Ground-Water Samples (all values, except pH and Specific Conductance, in mg/l)

Sample No*	Date Sampled	pH		Ionic Concentrations									Total Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$	Total Dissolved Solids	Specific Conductance (mmhos/cm at 25°C)	
		in Field	at Lab	Calcium	Magnesium	Sodium	Potassium	Bicar-bonate	Sulphate	Chloride	Nitrate as N	Total Iron				in Field	at Lab
1334	8/70		7.3	176	17	23	2.1	388	79	89	12	.05	318	512	740		1093
1335	8/70		7.3	168	18	28	2.4	409	112	60	.2	.10	335	494	670		984
1380	6/26/74	6.9	7.4	125	12	26	1.4	223	26	22	12	.05	183	360	460	690	700
1430	6/26/74		7.7	22	8	270	8.7	727	8	128	<.2	1.6	596	88	880		1400
1450	6/25/74	7.7	7.8	48	20	13	1.2	276	4	4	<.2	.40	226	204	254	440	390
1480	8/70		7.5	158	9	111	8.2	345	48	221	9.3	.05	283	432	1000		1329
1537	6/25/74	7.0	7.4	136	17	16	16	397	49	56	1.2	.35	325	408	550	900	800
1541	6/26/74	7.0	7.3	176	19	33	0	437	88	66	13	.63	358	520	700	200	1040
1563	8/70		7.6	131	2	5	2.0	276	70	7	11	.10	226	335	470		643
1601	6/26/74	7.5	7.7	51	17	18	1.5	414	3	3	<.2	.55	339	196	220	420	365
1663	6/26/74	7.2	7.4	112	30	11	2.2	250	67	36	.7	<.05	205	312	500	800	740
1665	6/26/74	7.4	7.6	82	22	4	1.5	317	47	4	<.2	<.05	260	296	300	520	480
1739	6/25/74	7.7	7.6	64	20	13	0	282	34	6	<.2	5.3	231	244	280	510	465
1744	6/25/74	7.4	7.3	134	17	8	.3	331	49	53	5.0	.15	271	404	520	750	740
1746	6/25/74	7.3	7.5	136	15	5	.3	320	49	65	2.0	<.05	262	400	600	800	730
2884	6/26/74		7.4	134	10	33	1.3	327	54	24	20.	<.05	268	376	560		790
2942	6/24/74	7.8	7.8	54	21	8	1.4	260	20	3	<.2	1.1	213	224	290	440	415
3066	6/24/74	7.5	7.4	72	20	19	1.6	266	22	47	.4	.45	218	264	400	600	570
3271	6/25/74	6.9	7.2	179	26	81	1.7	395	55	262	<.2	1.1	324	552	800	1450	960
3413	6/25/74	7.1	7.3	118	7	15	1.7	359	38	16	.4	.15	294	324	400	525	620
3588	6/24/74	7.6	7.7	30	15	34	1.3	251	3	5	<.2	.30	206	136	240	410	370
3612	6/25/74	6.9	7.3	171	20	9	1.1	367	57	19	33	<.05	301	508	730	1005	950
3614	6/24/74	6.9	7.3	110	18	16	1.6	361	26	42	<.2	.90	296	352	460	750	700
3626	6/24/74	7.4	7.6	53	17	9	1.3	254	5	1	<.2	.30	208	204	244	420	375
3679	6/25/74	7.9	7.7	40	34	13	2.0	310	2	2	<.2	.55	255	232	230	450	435
3769	6/26/74		7.3	171	16	30	2.1	384	62	111	<.2	.25	315	492	830		990
3907	6/25/74	7.6	7.7	48	17	27	1.2	289	2	2	<.2	1.2	237	190	240	500	445
3997	6/25/74	7.1	7.4	58	23	22	.9	300	23	14	<.2	.25	246	240	280	420	485
4043	6/26/74	7.5	7.7	64	13	2	1.3	205	22	3	<.2	1.7	168	212	207	400	375

Table 10 continued

Sample No*	Date Sampled	pH in Field	pH at Lab	Calcium	Magnesium	Sodium	Potassium	Bicar-bonate	Sulphate	Chloride	Nitrate as N	Total Iron	Total Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$	Total Dissolved Solids	Specific Conductance (mmhos/cm at 25°C) in Field	Specific Conductance (mmhos/cm at 25°C) at Lab
				Ionic Concentrations													
4095	6/26/74	7.6	7.7	61	14	2	1.3	273	25	3	.8	<.05	224	198	244	400	355
4188	8/70		8.3	14	6	109	2.6	268	1	60	.18	.80	220	57	380		639
7690	6/24/74	7.3	7.6	82	16	3	1.3	296	29	2	<.2	.08	243	268	340	510	480
7692	6/24/74	7.4	7.5	67	11	3	1.3	255	1	1	<.2	2.0	209	212	240	400	370
7705	6/24/74	7.1	7.4	127	16	9	1.1	320	25	71	2.0	<.05	262	380	600	800	740
8665(2)	6/24/74	7.0	7.3	141	23	25	2.5	458	48	42	5.4	.05	376	448	600	950	900
8065(1)	6/24/74	7.3	7.5	75	19	3	1.3	260	29	3	<.2	.60	213	268	300	500	440
8239	8/70	-	7.6	14	5	4	.9	274	17	4	3.0	.10	226	204	350	-	471
8395	6/26/74		7.5	93	17	5	1.5	281	36	11	2.2	.05	230	274	340		510
8760	6/24/74	7.4	7.6	82	10	3	1.1	367	24	6	4.0	.20	201	244	300	500	445
10220	6/25/74	7.4	7.4	104	16	5	2.1	407	11	3	<.2	2.3	334	324	340	625	580
11219	6/25/74	6.7	7.0	222	39	46	4.2	595	155	119	<.2	.30	198	156	212	480	375
8212	6/24/74	7.2	7.5	86	13	5	1.4	265	30	13	2.4	.95	217	268	340	500	500
10992	6/26/74	7.5	7.6	51	17	25	2.2	268	3	22	<.2	.35	220	200	270	520	450

*Locations of sampling points are shown on Map 12



WATER RESOURCES REPORT 8

Maps and Figures in Pocket:

KEY MAP

LEGEND

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

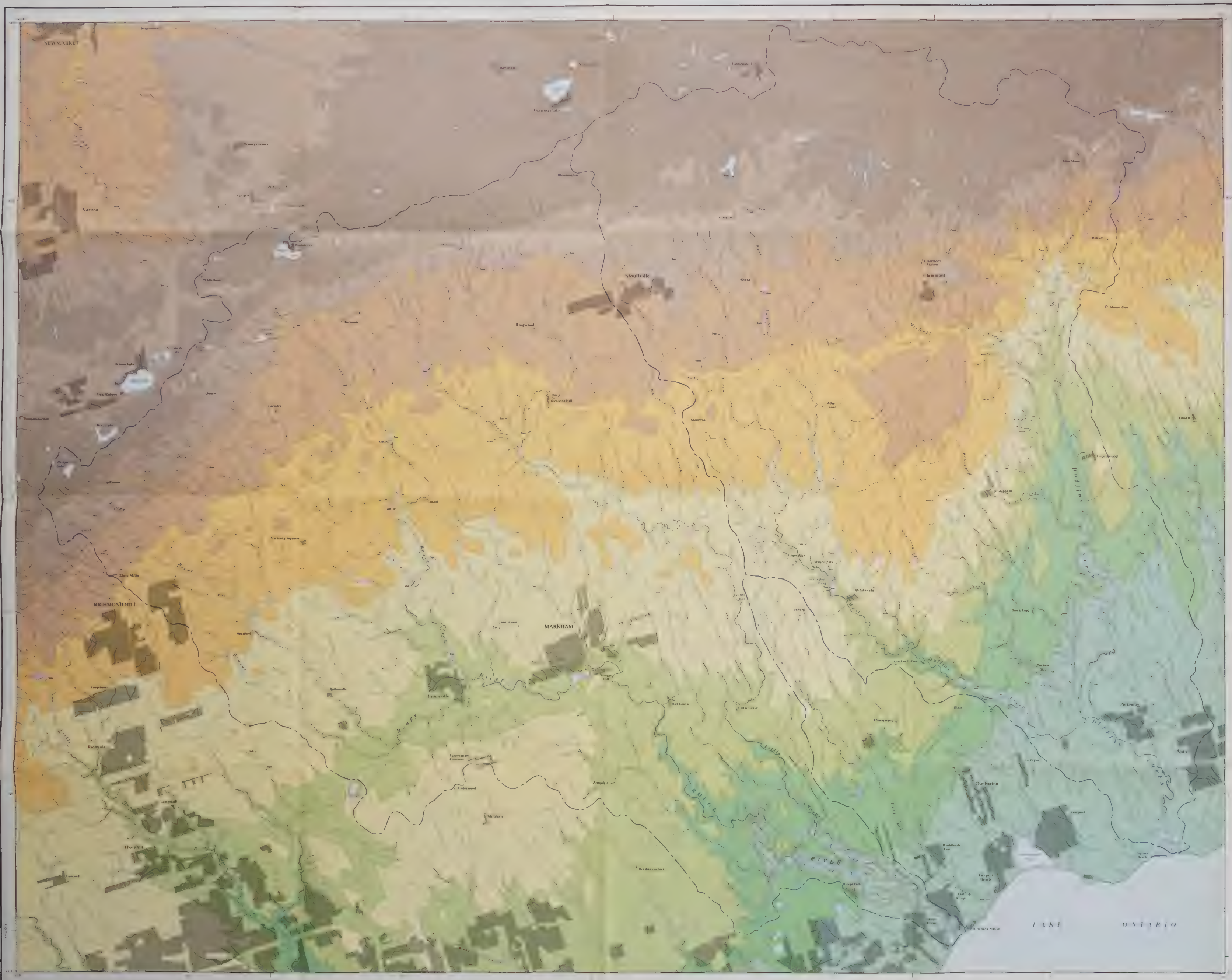
DUFFINS CREEK-ROUGE RIVER DRAINAGE BASINS

MAP 6

LOCATIONS OF WATER WELLS

Scale 1:50 000

MAP 2123



KEY MAP

Scale 1 inch to 50 miles

LEGEND

Drainage basin boundary

Dam

Population centre

Topographic contour, interval 25 feet

Note: All elevations in feet above mean sea level

ELEVATION TINTS

Metres | Feet

Physical Characteristics of Major Streams

Stream	Length (miles)	Approx. el. near source (feet)	Total drop in streambed el. (feet)	Stream gradient (ft./mile)
Rouge River	27.2	985	740	27.2
Rouge Creek	20.5	1000	741	36.1
Duffins Creek	15.4	1000	755	
West Duffins Creek	16.8	1000	730	43.5
[illegible] Creek	7.5	625	380	50.7

Reference: Ont. Dept. Planning & Dvt. 1956

Cartography by D. Griffin

Base map derived from 1:25 000 and 1:50 000 sheets of the National Topographic Series

To accompany Water Resources Report 8

Ontario

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

DUFFINS CREEK-ROUGE RIVER DRAINAGE BASINS

MAP 1

PHYSIOGRAPHY AND DRAINAGE

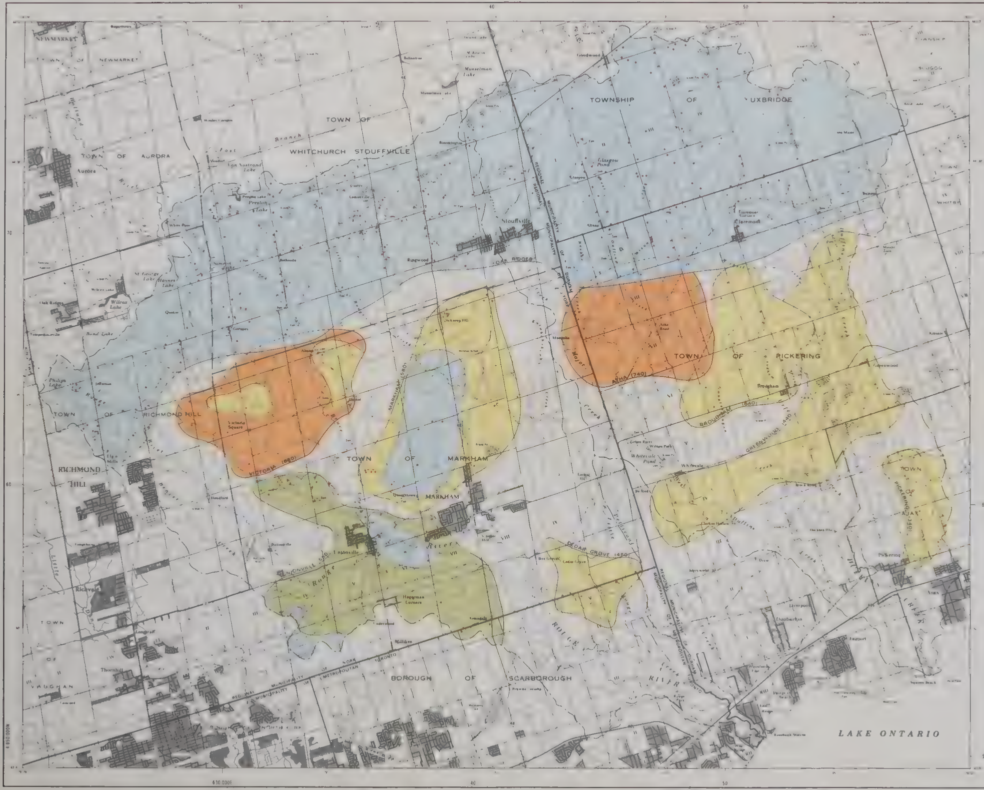
Scale 1:50,000

1 inch equals 0.79 miles

Miles

Kilometres

MAP 2119



LEGEND

- Area where wells are generally yield less than 10 gpm. Supplies are generally adequate for domestic and stock purposes
- Area where wells are likely to yield 10-25 gpm. Supplies are generally plentiful for domestic and stock purposes and usually adequate for small-scale industrial and commercial uses
- Area where wells are likely to yield 25-50 gpm. Supplies are generally adequate for medium-scale industrial and commercial purposes but only poor to fair as a source for irrigation
- Area where wells are likely to yield more than 50 gpm. Supplies are generally adequate for most purposes. The Markham and Unionville aquifers are capable of yielding more than 350 gpm to municipal wells at the respective well sites, and it is expected that there are areas in the Oak Ridges aquifer complex where well yields can readily exceed 100 gpm.
- Test hole drilled in overburden
- Test hole drilled in bedrock
- Drilled well in overburden
- Drilled well in bedrock
- Dug or bored well in overburden
- Drilled municipal well in overburden
- Flowing well
- Abandoned well
- Estimated specific capacity of well (gpm/ft), this represents the amount of water available from the well, in gpm per foot of available drawdown
- Specific capacity estimate not available because of insufficient data in the water-well record

Note:

The probable well yields shown on the map represent generalizations interpreted on the basis of data available mainly from domestic well records. These wells are usually developed to meet domestic demands, i.e., small quantities of water, and are not highly efficient. Consequently it is often possible, with proper well construction and development, to increase the efficiency and therefore the potential yield of wells. For this reason it is possible that in some parts of the aquifers properly developed, efficient wells may yield substantially higher quantities of water than that shown on the map. Conversely, highly inefficient wells may yield smaller quantities of water.

SOURCES OF INFORMATION

Interpretations by U. Sibul and K. T. Wang. Interpretations are based on water-well records on file with the Ontario Ministry of the Environment as of December 1974, and on the basis of MOE test drilling during 1970, 1971 and 1974.

Cartography by D. Griffin.

Base map derived from 1:25,000 and 1:50,000 maps of the National Topographic series.

To accompany Water Resources Report 8

Ontario
MINISTRY OF THE ENVIRONMENT
Water Resources Branch

DUFFINS CREEK-ROUGE RIVER DRAINAGE BASINS

MAP 9

AVAILABILITY OF WATER FROM MAJOR UPPER AQUIFER SYSTEMS IN THE OVERBURDEN

Scale 1:100 000
1 inch equals 1.58 miles

LEGEND

Area where wells are likely to yield less than 10 gpm. Supplies are generally adequate for domestic and stock purposes

Area where wells are likely to yield 10 to 25 gpm. Supplies are generally plentiful for domestic and stock purposes and usually adequate for small-scale industrial and commercial uses

Area where wells are likely to yield 25 to 50 gpm. Supplies are generally adequate for medium-scale industrial and commercial purposes, but only possibly as a source for irrigation

Area where wells are likely to yield more than 50 gpm. Supplies are generally adequate for most purposes. The Markham and Unionville aquifers are capable of yielding more than 350 gpm to municipal wells at the respective well sites

Test hole drilled in overburden

Test hole drilled in bedrock

Drilled well in overburden

Drilled well in bedrock

Dug or bored well in overburden

Drilled municipal well in overburden

Flowing well

Abandoned well

Estimated specific capacity of well (gpm/ft); this represents the amount of water available from the well in gpm per foot of available drawdown

Specific capacity estimate not available because of insufficient data in the water-well record

Note

The probable well yields shown on the map represent generalizations interpreted on the basis of data available mainly from domestic well records. These wells are usually developed to meet domestic demands, i.e. small quantities of water, and are not highly efficient. Consequently it is often possible, with proper well construction and development, to increase this efficiency and therefore the potential yield of wells. For this reason it is expected that in some parts of the aquifers properly developed, efficient wells may yield substantially higher quantities of water than those shown on the map. Conversely, highly inefficient wells may yield smaller quantities of water

SOURCES OF INFORMATION

Interpretations by [illegible] Sibul and K. [illegible] Wang. Interpretations are based on water-well records on file with the Ontario Ministry of the Environment as of December 1974, and on the basis of MOE test drilling during 1970, [illegible] and 1974.

Cartography by [illegible] Griffin

Base map derived from 1:25,000 and 1:50,000 maps of the National Topographic series

To accompany Water Resources Report 8

Ontario

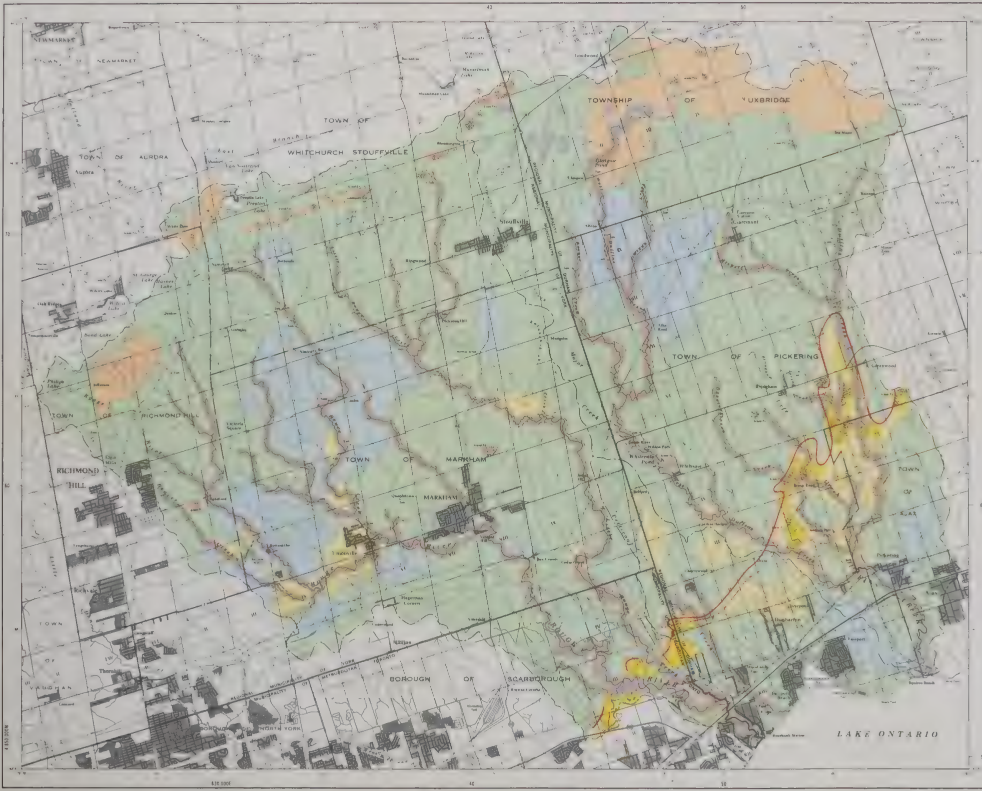
MINISTRY OF THE ENVIRONMENT
Water Resources Branch

DUFFINS CREEK-ROUGE RIVER DRAINAGE BASINS

MAP 10

AVAILABILITY OF WATER FROM MAJOR LOWER AQUIFER SYSTEMS IN THE OVERBURDEN

Scale 1:100 000
1 inch equals 1.58 miles



LEGEND

CENOZOIC

PLEISTOCENE

RECENT

Alluvial deposits

Swamp deposits

WISCONSINAN

Fine grained lacustrine and pond deposits

Coarse grained lacustrine and pond deposits

Kame, ice contact and outwash deposits ... of the basin

Beach deposits well sorted and stratified sands and gravels south of the Lake Iroquois shoreline

Glacial deposits (undifferentiated) mainly silty sand till

Geological boundary, approximate

Lake Iroquois shoreline

Bedrock outcrop

SOURCES OF INFORMATION

Cartography by D. Griffin

Base map derived from 1:25 000 and 1:50 000 sheets of the National Topographic series

To accompany Water Resources Report 8

Ontario

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

DUFFINS CREEK-ROUGE RIVER DRAINAGE BASINS

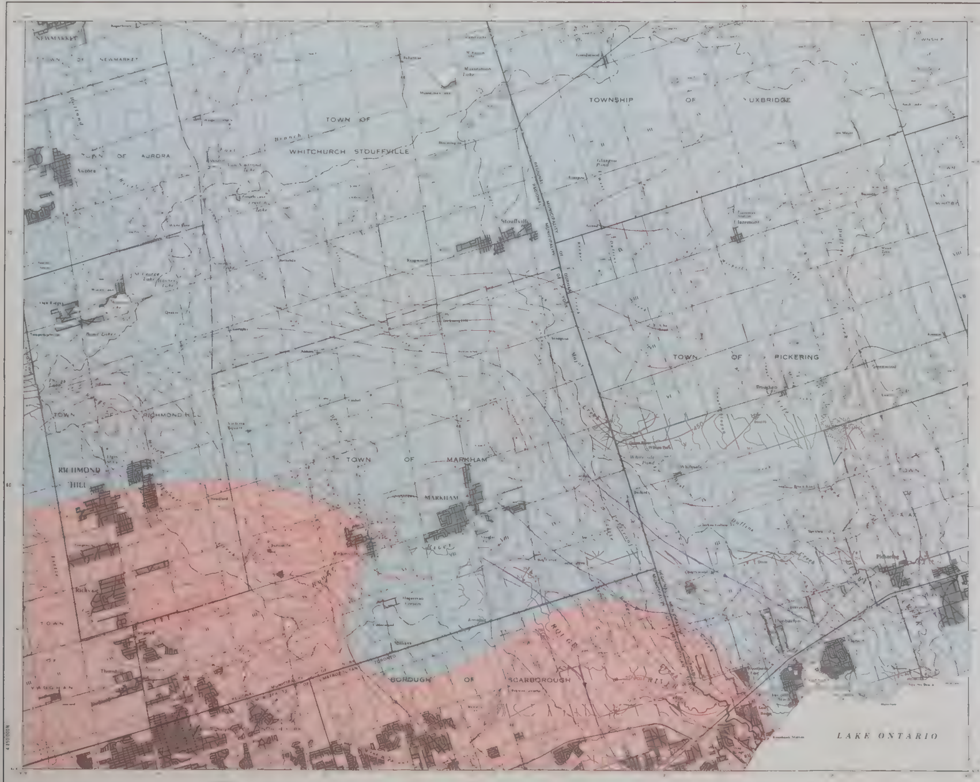
MAP 5

SURFICIAL GEOLOGY

Scale 1:100 000

1 inch equals 1.58 miles

MAP 2122



Transverse Mercator Projection

LEGEND

PALEOZOIC

UPPER ORDOVICIAN

- Georgian Bay Formation: shale with limestone interbeds
- Whitby Formation: shale
- Geological boundary, approximate
- Bedrock surface contour, interval [illegible] feet
- Bedrock well, approximate elevation of top of rock
- Deep overburden well, approximate elevation of bottom of well
- Bedrock outcrop, approximate elevation of top of rock (where shown)
- Approximate location of assumed bedrock valley

SOURCES OF INFORMATION

Bedrock geology after Hewitt 1972; bedrock topography [illegible] on the basis of water well records on file with the Ontario Ministry of the Environment as of December 1974.

References

Haefeli, C. [illegible] Dept. Energy Mines Res. [illegible]
Hewitt, D.F. 1964: Industrial mineral resources of the Markham-Newmarket area; Ont. Dept. Mines Ind. Min. Rep. 24, Map 2[illegible].
[illegible] 1972: Paleozoic geology of southern Ontario; Ont. Div. Mines Geol. Rept. [illegible] Map 2254.
Karrow, P.F. 1967: Pleistocene geology of the Scarborough area; Ont. Dept. Mines Geol. Rept. 46.
[illegible] 197[illegible]: Pleistocene geology of the Thornhill area; Ont. Dept. Mines Ind. Min. Rept. [illegible]
Ostry, R.C. [illegible]
Royer, [illegible] Ont. Dept. Mines [illegible]
Terra Surv. Ltd. [illegible] North Pickering [illegible] ment Project, Min. Treas. Ec. and Intergov. Affairs.
Watt, A.K. 1957: Pleistocene geology and ground-water resources of the Township of North York, York County; Ont. Dept. Mines [illegible] Part 7.

Cartography by [illegible]

Base map derived from 1:25 000 and 1:50 000 sheets of the National Topographic series

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

DUFFINS CREEK-ROUGE RIVER DRAINAGE BASINS

MAP 3
BEDROCK GEOLOGY AND TOPOGRAPHY

Scale 1:100 000
1 inch equals 1.58 miles

MAP 2120

GENERAL AQUIFER CHARACTERISTICS

AQUIFER SYSTEM	APPROXIMATE SURFACE AREA (sq mi)	PREDOMINANT MATERIAL	AVERAGE SATURATED THICKNESS (ft)	AVERAGE DEPTH TO TOP OF SYSTEM (ft)	AVERAGE DEPTH TO STATIC WATER LEVEL (ft)	APPROX T* (gpd/ft)
Oak Ridges	86	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Markham	14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Unionville	15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	sand	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	sand	[illegible]	[illegible]	[illegible]	[illegible]
Greenwood	16	sand	[illegible]	[illegible]	[illegible]	[illegible]
Atha	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

*Note: [illegible]

AQUIFER COEFFICIENTS AT SPECIFIC SITES, DETERMINED FROM DETAILED PUMPING TESTS*

WELL NUMBER	PURPOSE OF WELL	AQUIFER TESTED	T (gpd/ft)	S	L (gpd/ft³)	REFERENCE
3768	Unionville municipal well #3	Upper Unionville	3750	2.3×10^{-4}	10^{-3}	.
3899	Markham municipal well #2	Upper Markham	52,800	NA	NA	4
4375	Industrial well	Oak Ridges	10,800	4.4×10^{-5}	2×10^{-3}	6
4709	MOE test well	Greenwood	14,410	6.7×10^{-4}	NA	6
8211	Stouffville municipal well #8	Oak Ridges	8380	2.5×10^{-4}	2×10^{-3}	2

*Note. The coefficients of transmissibility (T), storage (S) and leakage (L) have been calculated on the basis of long term pumping tests for which drawdown time or drawdown distance curves were available. Either the Hantush (1964) leakage or Jacob (1953) simplified formulae were used depending on the pumping test data. NA indicates that pertinent data were not available for calculation of the parameter. The sources of data are indicated by the appropriate references.

SOURCES OF INFORMATION

[illegible] are based on water well records on file with the Ontario Ministry of the Environment as of December 1974, and on the basis of M.O.E. test drilling during 1970, 1971 and 1974.

References

1 [illegible] ment Ltd. Unionville Area.

2 Hydrology Consultants Ltd. 1965. Pumping tests on a production well at the Town of Stouffville.

3 Hydrology Consultants Ltd., 1975. New Toronto International Airport Ground water study. Transport Canada.

4 International Water Supply Ltd. 1964. Unpublished data on Markham Well #2.

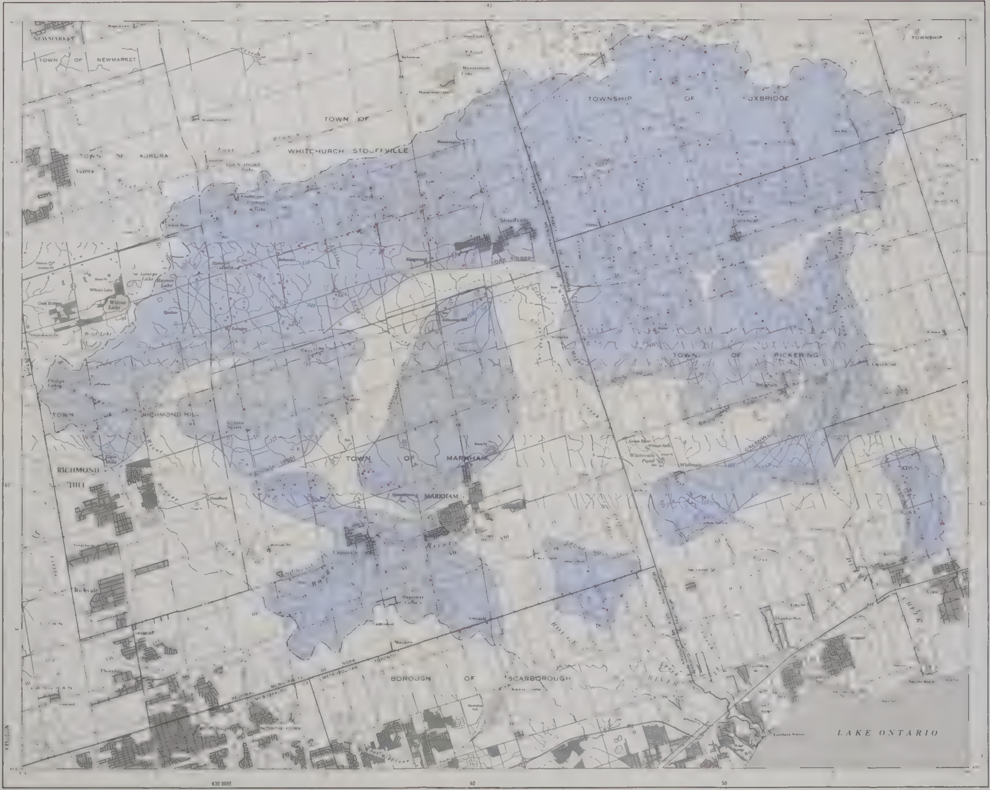
5 George H. Mayhew and Assoc. 1970. Analysis of the test pumping of the well at [illegible] operatives Ontario. Police Village of Claremont. Pickering Township. County of Ontario. Ontario.

6 Ministry of the Environment, 1970. Unpublished data on file.

7 Ministry of the Environment, 1974. Unpublished data on file.

Cartography by D. Griffin

Base map derived from 1:25 000 and 1:50 000 sheets of the National Topographic [illegible]



LEGEND

ATHA 745 — Approximate boundary of aquifer, aquifer name (approximate mean elevation of top of aquifer)

Piezometric surface elevation contour in aquifer (feet above m.s.l.), interval 25 feet (50 feet in Oak Ridges aquifer)

Test hole drilled in overburden

Test hole drilled in bedrock

Drilled well in overburden

Drilled well in bedrock

Dug or bored well in overburden

[illegible]

Abandoned well

[illegible]

To accompany Water Resources Report 8

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

DUFFINS CREEK-ROUGE RIVER DRAINAGE BASINS

MAP 7

MAJOR UPPER AQUIFER SYSTEMS IN THE OVERBURDEN

Scale 1:100 000

MAP 2125

SUMMARY OF MAJOR GROUND-WATER WITHDRAWALS[1]

MAP REFERENCE	SOURCE	WATER-WELL RECORD NUMBER	AQUIFER	AUTHORIZED BY PERMIT gpm	AUTHORIZED BY PERMIT mgd	CONSUMPTION (1975)[2] mgd	CONSUMPTION (1975)[2] as % of Author	REMARKS
MUNICIPAL SUPPLY								
MS8	1 well	8211	OR	350	.37	0.73	53	Stouffville #8 well
MS5	1 well	8212	OR	700*	1.01*			Stouffville #5 well
MO1	1 well	1464	OR	250	.43	0.13	13	Oak Ridges #1 well
MO2	1 well	9125	OR	400	.58			Oak Ridges #2 well
MM1	1 well	4170	LM	1000*	1.44*	1.51	52	Markham #1 well
MM2	1 well	3899	UM	1000	1.44			Markham #2 well
MU1	1 well	3782	LU	240	26			Unionville #1 well
MU2	1 well	10992	LU	240	35	0.45	54	Unionville #2 well
MU3	1 well	3768	UU	150	22			Unionville #3 well
MDM1	1 well	3149	LU	350*	43*			Don Mills #1 well
MDM2	1 well	3148	LU	350*	43*	1.49	58	Don Mills #2 well
MDM3	1 well	3145	LU	650	[illegible]			Don Mills #3 well
MSP7	1 well	10842	LU	700	1.00			Steeles-Pharmacy #7 well
Total				6280	8.75	4.31	Avg.=49	
INDUSTRIAL SUPPLY								
I 1	2 wells	8218 8219	OR OR	600	.86	35	41	sand & gravel wash
I 2	1 pit	—	—	96	06	.04	66	sand & gravel wash
I 3	1 well	8400	OR	40	.06	.03	50	sand & gravel wash
I 4	1 well	3917	OR	600	.47	.11	23	sand & gravel wash
I 5	1 pit	—	—	115	.55	.18	33	sand & gravel wash
I 6	2 wells	9694 6324	OR OR	35	05	02	40	processing, boiler feed
I 7	1 well	9694	OR	350	.50	.26	52	sand & gravel wash
I 8	1 well	4375	OR	185	27	.09	33	processing
I 9	1 well	1482	—	1040	.94	.18	19	fish production
Total				3061	3.76	1.26	Avg.=34	
GOLF COURSE IRRIGATION								
G 1	1 well	3697	LU	60	.07	.04	57	storage recharge
G 2	1 well	3327	—	40	.05	.02	40	storage recharge
G 3	1 well	5368	—	145	.12	.04	33	storage recharge
G 4	5 wells	8869 3524 [illegible] 9433 9443	LU — — —	[illegible]	[illegible]	.26	74	storage recharge
G 5	1 well	2979	OR	[illegible]	[illegible]	[illegible]	43	storage recharge
G 6	1 well	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	storage recharge
G 7	1 well	[illegible]	OR	25	[illegible]	[illegible]	[illegible]	storage recharge
Total				710	.81	.47	Avg.=58	
AGRICULTURAL IRRIGATION								
A 1	2 wells	1394 3398	— —	457	[illegible]	.10	16	turf sod irrigation
A 2	3 dugouts	—	—	367	04	.04	100	crop irrigation
A 3	1 well	8867	LU	15	.02	.01	50	crop irrigation
A 4	1 well	4886	—	15	01	.01	100	nursery irrigation
A 5	1 dugout	—	—	96	.06	.02	33	crop irrigation
A 6	1 dugout	—	—	500	.45	.13	29	crop irrigation
Total				1450	1.20	[illegible]	Avg.=26	
PRIVATE RECREATION SUPPLY								
R 1	1 well	no record	OR	20	.03	.03	100	pond recharge
R 2	1 well	no record	OR	25	.04	.04	100	pond recharge
R 3	1 well	8668	OR	20	03	.03	100	pond recharge
R 4	1 well	8063	OR	30	.04	.04	100	pond recharge
Total				95	14	.14	Avg.=100	
BASIN TOTAL				11596	14.66	6.49	Avg.=44	

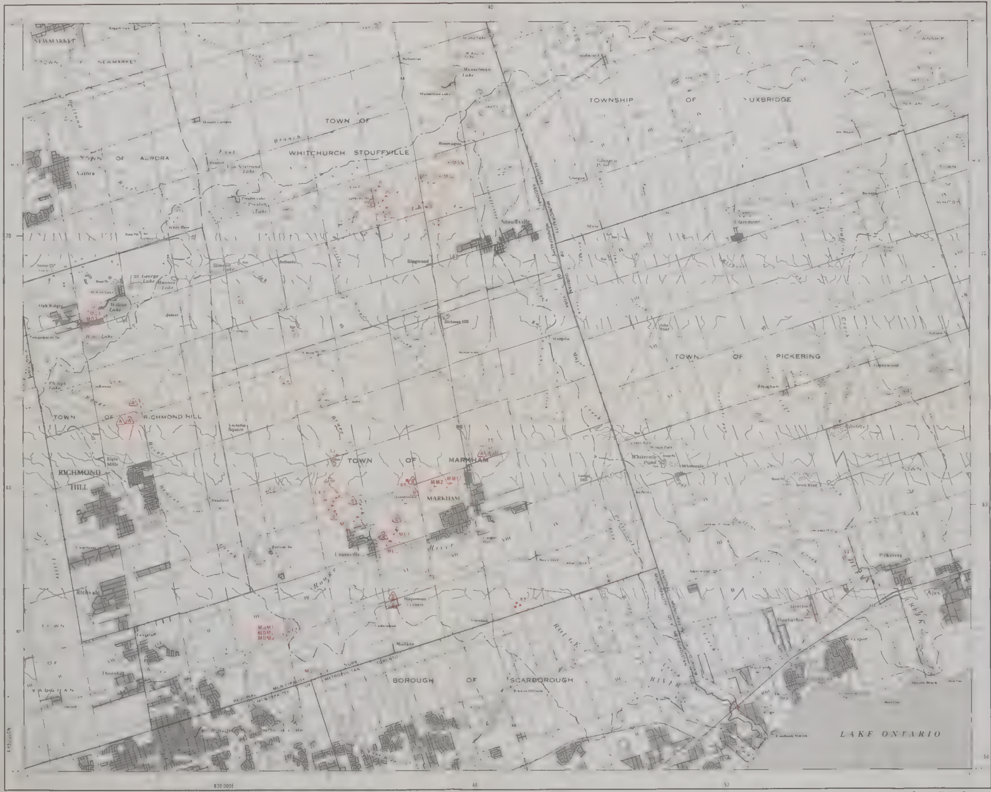
[1]Major withdrawals refer to the use of ground water from individual sources at rates exceeding 10,000 gallons per day.

[2]Values for Industrial Supply, Golf Course Irrigation, Agricultural Irrigation and Private Recreational Supply are based on projections of 1973 data.

*These withdrawals are not authorized by Permit; rates and amounts stated represent capacities determined for the source.

SUMMARY OF GROUND WATER SUPPLY INTERFERENCE CASES

MAP REFERENCE	ALLEGED SOURCE OF INTERFERENCE	NUMBER OF VALID CASES
A	Dewatering at construction site or gravel pit	7
B	Municipal withdrawal	5
C	Irrigation withdrawal	[illegible]
D	Withdrawal for private or recreational supply	3



Transverse Mercator Projection

LEGEND

- Major ground water withdrawal, refer to table for summary
- Location of ground water supply interference case, refer to table for summary
- Municipal well
- Industrial well
- Industrial pit
- Irrigation well
- Irrigation dugout pond
- Recreational well
- Flowing well

SOURCES OF INFORMATION

Ministry of the Environment internal files on water well interference complaints

Ministry of the Environment records in connection with the Permit to Take Water program

Water well records on file with the Ontario Ministry of the Environment as of December 1974

Base map derived from 1:25 000 and 1:50 000 sheets of the National Topographic series

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

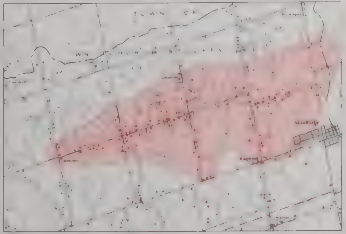
DUFFINS CREEK-ROUGE RIVER DRAINAGE BASINS

MAP 14

MAJOR GROUND-WATER WITHDRAWAL AND WATER SUPPLY INTERFERENCE SITES

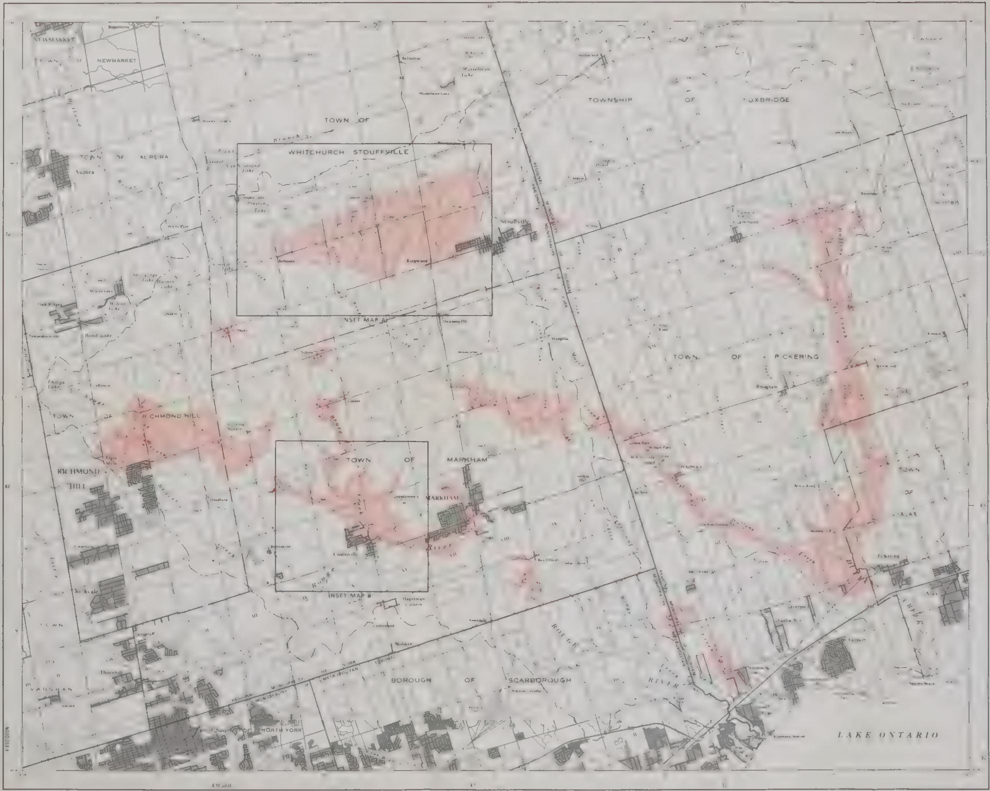
Scale 1:100 000

MAP 2132



INSET MAP A
Scale 1 75,000

INSET MAP B
Scale 1 50 000



LEGEND

Bored or dug well, not flowing, in inset maps A and B only

Drilled bedrock well, not flowing, in inset maps A and B only

SOURCES OF INFORMATION

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

DUFFINS CREEK-ROUGE RIVER DRAINAGE BASINS

MAP 15

FLOWING WELL AREAS

Scale 1 100 000

STREAM - GAUGING STATIONS SUMMARY

STATION NUMBER	STATION NAME	DRAINAGE AREA (sq mi)	TYPE OF GAUGE OPERATION	PERIOD OF RECORD
02HC022	Rouge River near Markham	72	recording, continuous	1961
02HC103	Rouge River at Scarborough	82.9	recording, continuous	1974 *
02HC028	Little Rouge Creek near Locust Hill	30	recording, continuous	1963 *
02HC104	Little Rouge Creek at Scarborough	42.7	recording, continuous	1974 *
02HC036	Katabokokonk Creek above Locust Hill	1.4	recording, continuous	1974 *
02HC105	Petticoat Creek near Dunbarton	7.0	recording, continuous	1974 *
02HC019	Duffins Creek below Arthur Percy Dam	36.1	manual, seasonal recording, continuous	1960-1962 1963 *
02HC006	Duffins Creek at Pickering	96.0	manual, seasonal manual, continuous recording, continuous recording, seasonal	1945-1948 1949-1958 1959-1971 1972 *
02HC041	West Duffins Creek near Altona	6.8	recording, continuous	1974 *
02HC038	West Duffins Creek above Green River	18.5	recording, continuous	1974 *
02HC026	West Duffins Creek at Green River	36.3	manual, continuous manual, continuous recording, continuous	1963-1968 1970-1971 1974 *
02HC106	West Duffins Creek near Pickering	50.9	recording, continuous	1974 *
02HC046	Wixon Creek below Altona	4.1	recording, continuous	1974 *
02HC040	Reesor Creek near Altona	5.8	recording, continuous	1974 *
02HC039	Reesor Creek above Green River	14.8	recording, continuous	1974 *
02HC035	Stouffville Creek below Stouffville	5.9	recording, continuous	1974 *
02HC037	Major Creek above Green River	1.9	recording, continuous	1974 *

*Operational in December 1976

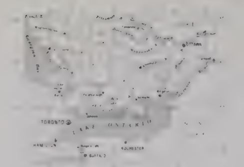
METEOROLOGIC STATIONS SUMMARY

STATION NAME	STATION NUMBER	RECORDS FROM Year	RECORDS FROM Month	SYNOPTIC REPORTS	HOURLY WEATHER	TEMPERATURE	PRECIPITATION	RATE OF RAINFALL	WIND MILEAGE	SUNSHINE
Brougham	6151000	1965	08				X			
Bruces Mill	615J02G	1968	12				X			
Claremont	6151545	1962	03				X			
Frenchman's Bay	6152606	1959	06				X			
Markham	6154887	1967	02				X			
Markham MTRCA*	6154890	1964	07				X	X		
Markham OWRC*	6154992	1961	10			X	X			
Markham Waterworks OWRC*	6154994	1961	10				X			
Oak Ridges*	6156722	1918	06	X	X	X	X	X	X	X
Pickering	6156613	1965	10				X			
Pickering Audley	6156615	1958	08			X	X			
Richmond Hill	6157012	1959	06			X	X			
Richmond Hill OWRC	6157014	1960	06			X	X			
[illegible]	[illegible]	[illegible]	[illegible]				[illegible]			
Stouffville	6158080	1960	10				X			
Unionville*	6159058	1960	11				X			
Wilcox Lake	6168610	1960	07			X	X			

*Records may not be continuous

OBSERVATION WELLS SUMMARY

WELL NO	TYPE	GROUND ELEVATION (ft AMSL)	DIAM (in)	TOTAL DEPTH (ft)	MATERIAL	RECORD START (mo/yr)	RECORD END (mo/yr)	METHOD OF MEASUR'T	OWNER (in 1974)	REMARKS
106	drilled	800	8	135	sd & gr	8/63	*	Stevens Type F recorder	Regional Municipality of York	Observation well for Don Mills wells 1 2 3
301	bored	935	48	23	sd & gr	6/70	*	"	H. McDonnell	Water table measur't
302	bored	830	48	20	sd till	6/70	*	"	L. Bennett	Water table measur't
303	bored	330	48	44	sd	6/70	11/78	"	H. Carey	Precip. gauge at site from 6 71 to 10 71
304	drilled	834	6	439	gr	6/70	11 75	Stevens Type A35 recorder	H. Burton	Water well record 1666 precip. gauge at site from 6 70 to 10 70
305	bored	778	48	20	sd till	6/70	*	Stevens Type F recorder	M. Larkin	Water table measur't
306	bored	908	48	21	sd & gr	6 70	1/73	"	P. McNamara	Precip. [illegible] from 6 71 to 11 71
308	drilled	378	6	16	silt	1 71	2/76	Stevens Type A35 recorder	MTRCA Greenwood C.A.	Water table measur't water well record 5089 MOE test well
330	drilled	815	6	12	sd	1/71	*	"	MTRCA Claremont C.A.	Water table measur't water well record 5090 [illegible]
[illegible]	[illegible]	815	2	41	sd till	12/70	*	manual	[illegible]	[illegible]
[illegible]	[illegible]	815	2	70	sd	12/70	*	manual	[illegible]	[illegible]
[illegible]	[illegible]	818	2	183	sd & gr	12/70	*	manual	[illegible]	[illegible]
[illegible]	[illegible]	818	2	231	sd	12/70	*	manual	[illegible]	[illegible]
[illegible]	[illegible]	370	2	48	sd	12/70	*	manual	[illegible]	[illegible]
[illegible]	[illegible]	370	2	80	sd till	12/71	*	manual	[illegible]	[illegible]
[illegible]	[illegible]	815	2	34	sd & gr	2/71	*	manual	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	2	88	sd & gr	2/71	*	manual	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	6	83	sd & gr	5/74	*	Stevens Type A35 recorder	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	6	30	sd	5/74	*	"	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	6	171	sd	10/74	*	Stevens Type F [illegible]	[illegible]	[illegible]



KEY MAP

Scale 1 inch to 100 miles

LEGEND

Streamflow gauging station

Cartography by D. Griffin

Base map derived from 1:25 000 and 1:50 000 sheets of the National Topographic series

To accompany Water Resources Report 8

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

DUFFINS CREEK-ROUGE RIVER DRAINAGE BASINS

MAP 2

HYDROMETRIC STATIONS 1976

Scale 1:100 000

MAP 2124

GENERAL AQUIFER CHARACTERISTICS

AQUIFER SYSTEM	APPROXIMATE SURFACE AREA (sq mi)	PREDOMINANT MATERIAL	AVERAGE SATURATED THICKNESS (ft)	AVERAGE DEPTH TO TOP OF SYSTEM (ft)	AVERAGE DEPTH TO STATIC WATER LEVEL (ft)	APPROX T* (gpd/ft)
Markham	22	sand, gravel	30	180	30	2700
Unionville	14	sand, some gravel	20	100	30	3700
Victoria	13	sand	10	150	20	2500
Brougham	12	sand	10	110	50	1300
Green River	6	sand	10	100	50	1600

*Note The approximate T (transmissibility) values have been calculated on the basis of short term pumping test data given in the water well records on file with the Ministry. The method of calculation is described by Ogden, 1965

AQUIFER COEFFICIENTS AT SPECIFIC SITES. DETERMINED FROM DETAILED PUMPING TESTS*

WELL NUMBER	PURPOSE OF WELL	AQUIFER TESTED	T (gpd/ft)	S	L (gpd/ft³)	REFERENCE
[illegible]	test well	Lower Unionville	8430	4.1×10^{-5}	7.3×10^{-3}	1
[illegible]	test well	Lower Unionville	2170	7.1×10^{-5}	3×10^{-4}	1
[illegible]	MOE-NPP test well	Lower Brougham	1800	4.5×10^{-4}	7×10^{-3}	7
[illegible]	TAAP test well	Lower Markham	3900	1.5×10^{-3}	NA	3

*Note The coefficients of transmissibility (T), storage (S) and leakage (L) have been calculated on the basis of long term pumping tests for which drawdown time or drawdown distance curves were available. Either the Hantush (1964) leakage or Jacob (1953) simplified formulas were used, depending on the pumping test data. "NA" indicates that pertinent data were not available for calculation of the parameter. The sources of data are indicated by the [illegible]

SOURCES OF INFORMATION

Aquifer interpretations by U. Sibul assisted by X.T. Wang and K. Inch. Interpretations are based on water well records on file with the Ontario Ministry of the Environment as of December 1974 and on the basis of M.O.E. test drilling during 1970, 1971 and 1974

References

1 Hydrology Consultants Ltd. 1964. Report on pumping tests by Hengran Development Ltd. Unionville Area
2 Hydrology Consultants Ltd. 1965. Pumping tests on a production well at the Town of Stouffville
3 Hydrology Consultants Ltd., 1975. New Toronto International Airport Ground water study. Transport Canada
4 International Water Supply Ltd. 1964. Unpublished data on Markham Well #2
5 George H. Mayhew and Assoc. 1970. Analysis of the test pumping of the well at United Co-operatives Ontario, Police Village of Claremont, Pickering Township County of Ontario, Ontario
6 Ministry of the Environment, 1970. Unpublished data on file
7 Ministry of the Environment 1974. Unpublished data on file

Cartography by D. Griffin

Base map derived from 1:25 000 and 1:50,000 sheets of the National Topographic Series

LEGEND

Approximate boundary of aquifer, aquifer name (approximate mean elevation of top aquifer)

Piezometric surface elevation contour in aquifer (feet above m.s.l.) interval 25 feet

Test hole drilled in overburden

Test hole drilled in bedrock

Drilled well in overburden

Drilled well in bedrock

Dug or bored well in overburden

Drilled municipal well in overburden

Drilled municipal well in bedrock

Abandoned well

Water well in aquifer: upper value (35) indicates depth (in feet) to static water level; a plus sign (+) before this value indicates that the water level is above ground surface by the indicated number of feet; lower value (90) indicates depth (in feet) at which water is found in the aquifer – this depth usually corresponds to the depth to the top of the aquifer

Not available

Flowing well: static water level is above ground surface

Notes.

1. The aquifers shown on this map represent those that have been interpreted on the basis of available geologic and hydrologic data obtained from water-well records on file with the Ministry of the Environment (locations shown on Map 6). The locations of the aquifer boundaries are interpretive approximations and are subject to modifications as new information becomes available.

2. On areas of the map where aquifers are not shown, it has not been possible to identify discreet aquifers because of insufficient data to interpret aquifer extent, or because of the complexity of local aquifer systems. In determining the occurrence of ground water in areas outside the shown aquifers, records of local water wells should be consulted to determine the type of successful wells (dug, bored, drilled etc.) in an area, the depth(s) to local water bearing zone(s), and the depth(s) of the static water level(s).

To accompany Water Resources Report 8

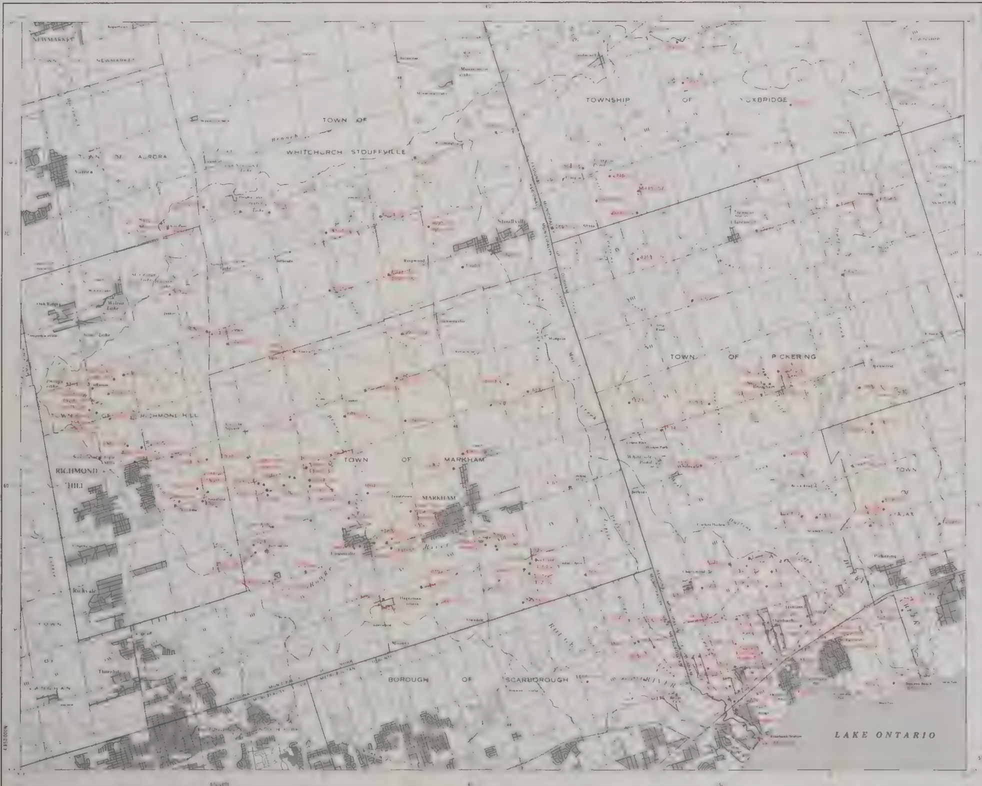
Ontario
MINISTRY OF THE ENVIRONMENT
Water Resources Branch

DUFFINS CREEK-ROUGE RIVER DRAINAGE BASINS

MAP 8

MAJOR LOWER AQUIFER SYSTEMS IN THE OVERBURDEN

Scale 1:100,000
1 inch equals 1.58 miles



KEY MAP

Sc... h to ... 0 miles

LEGEND

- Drilled wells in overburden
- Drilled wells in bedrock
- Dug or bored well in overburden
- Dug or bored well in bedrock
- Abandoned well
- 1288/26 Well number/well depth (feet)

Notes: 1. Black wells denote those reported as "dry" during drilling. Red wells denote those reported to contain poor quality water, or to contain specific problems as follows: sa - salty water, su - sulphurous water, g ... present.

2. All "dry" wells and specified water quality problems are based on reports by water-well drillers at time of construction of the well. Wells reported as dry are often drilled too shallow to encounter a water-bearing formation or the amount of water present is considered by the driller to be inadequate for the intended use(s).

SOURCES OF INFORMATION

Water-well records on file with the Ontario Ministry of the Environment as of December, 1974.

Cartography by D. Griffin

Base map derived from 1:25,000 and 1:50,000 sheets of the National Topographic Series.

To accompany Water Resources Report ...

Ontario

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

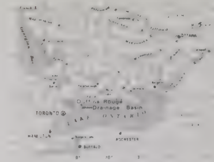
DUFFINS CREEK-ROUGE RIVER DRAINAGE BASINS

MAP 13

GROUND-WATER SUPPLY PROBLEMS

Scale 1:100 000

MAP 2133



KEY MAP

Scale 1 inch to 100 miles

LEGEND

SOURCES OF INFORMATION

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

DUFFINS CREEK-ROUGE RIVER DRAINAGE BASINS

MAP 4

OVERBURDEN THICKNESS

Scale 1 100 000

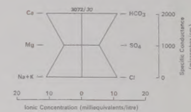
Transverse Mercator Projection

MAP 2121

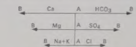
LEGEND

• 1384 Location of sampled well and well number

3072/30 Well number/depth of well (feet)



EXPLANATION OF HYDROCHEMICAL DIAGRAM



The lengths of the horizontal lines (A-B) indicate the concentrations of respective ions (in milliequivalents/litre) according to the indicated horizontal scale. The length of the vertical axis (line A-A-A) indicates the specific conductance of the water sample according to the indicated vertical scale. The main purpose of the diagrams is to facilitate the comparison of ground-water quality throughout the basin; generally, similar shapes indicate similar water qualities.

SOURCES OF INFORMATION

Water samples collected by D. Sharma, August 1970, and I. Stettner, June 1974.

Well information obtained from water-well records on file with the Ontario Ministry of the Environment.

Cartography by D. Griffin.

Base map derived from 1:25,000 and 1:50,000 sheets of the National Topographic series.

To accompany Water Resources Report 8

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MINISTRY OF THE ENVIRONMENT
Water Resources Branch

DUFFINS CREEK-ROUGE RIVER DRAINAGE BASINS

MAP 12
GROUND–WATER QUALITY

Scale 1:100,000
1 inch equals 1.58 miles

KEY MAP

Scale 1 inch to 100 miles

Transverse Mercator Projection

LEGEND

Shallow well less than 45 feet deep, approximate elevation of static water level in well

Water-level elevation contour; approximate interval 50 feet

Note: Only representative control points are shown in dense well areas

SOURCES OF INFORMATION

Static water-level elevations based on information derived from water-well records on file with the Ontario Ministry of the Environment as of December 1974

Cartography by D. Griffin

Base map derived from 1:25,000 and 1:50,000 sheets of the National Topographic series.

To accompany Water Resources Report 8

Ontario

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

DUFFINS CREEK-ROUGE RIVER DRAINAGE BASINS

MAP 11

CONFIGURATION OF WATER-LEVEL SURFACE IN SHALLOW WELLS

Scale 1:100,000
1 inch equals 1.58 miles

MAP 2129

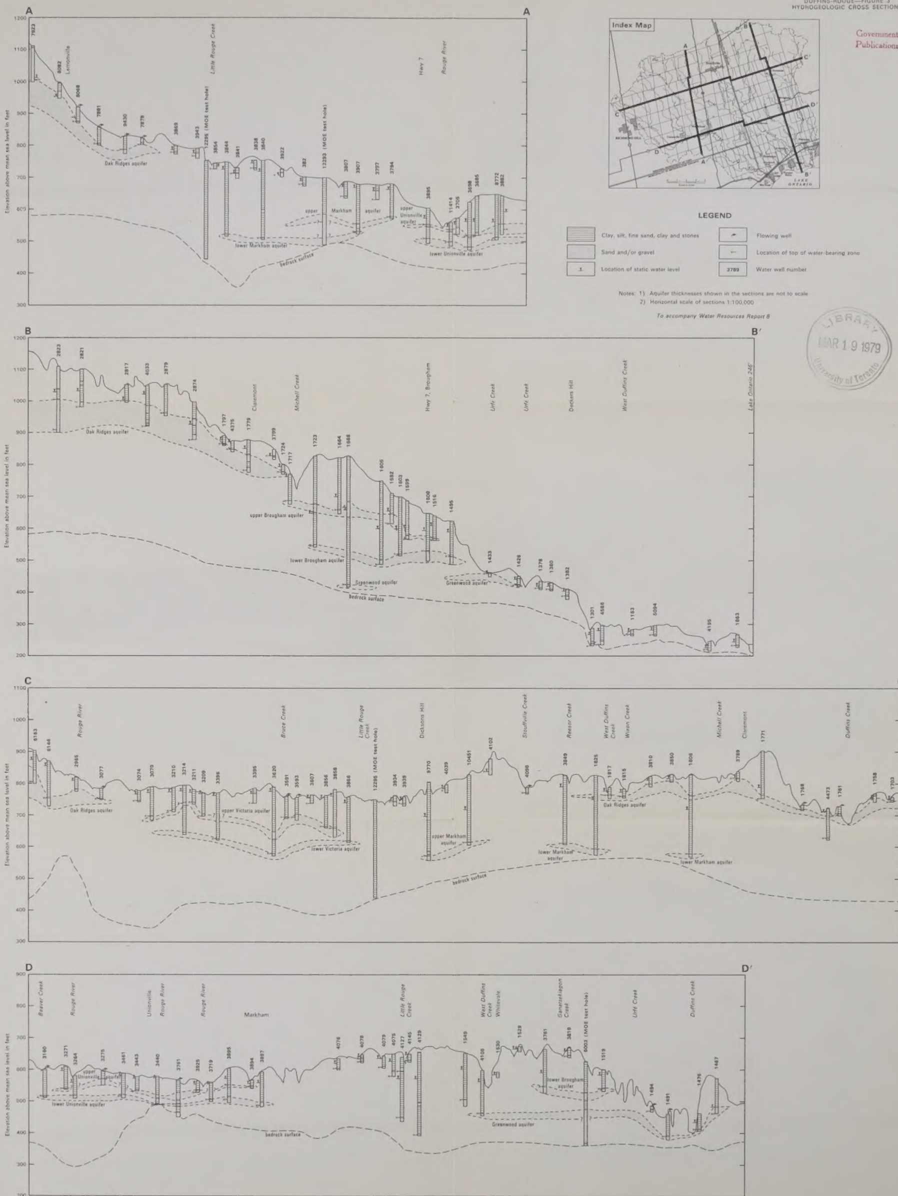

Figure 3. Hydrogeologic cross sections.